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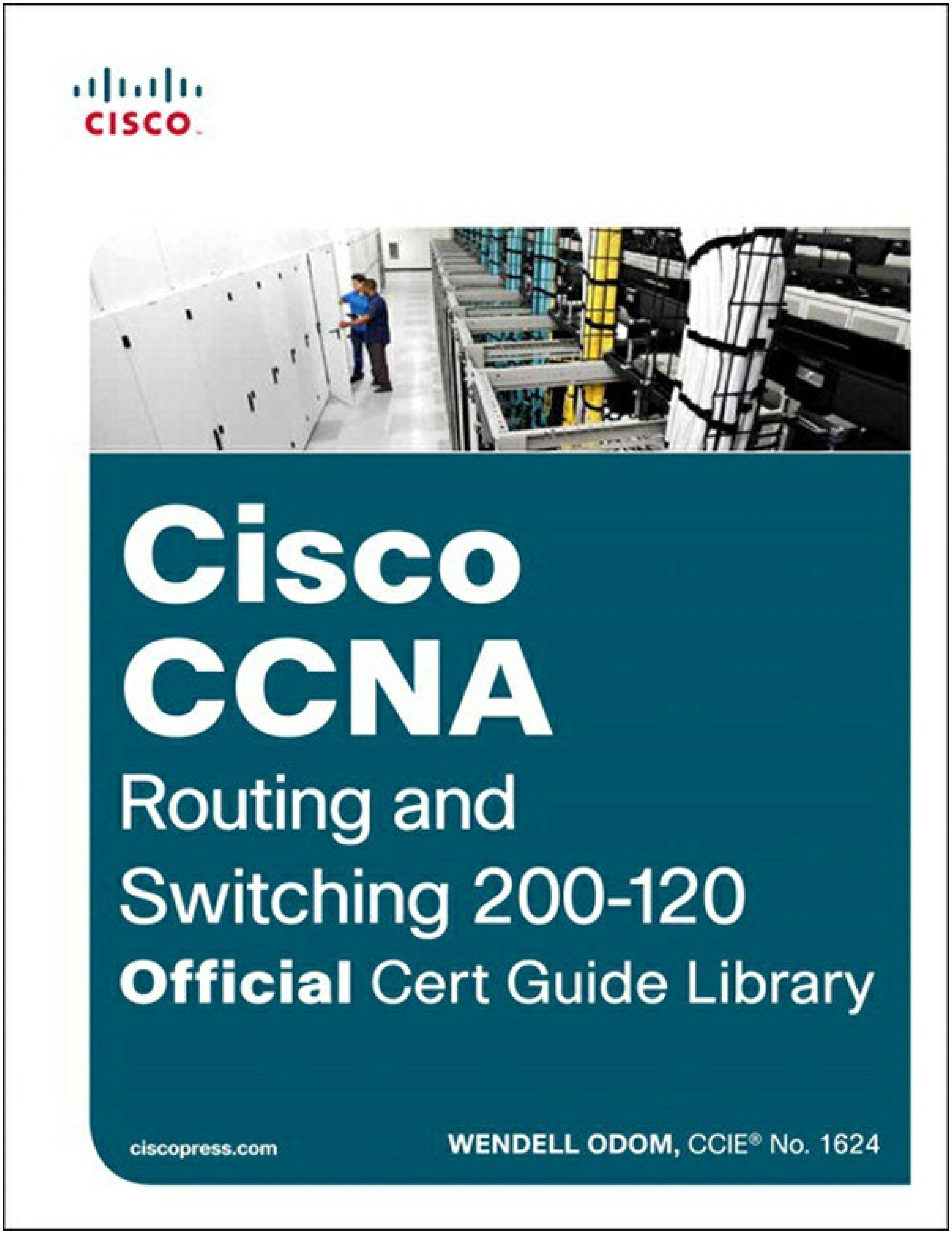

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About the Author

Wendell Odom, CCIE No. 1624, has been in the networking industry since 1981. He has worked as a network engineer, consultant, systems engineer, instructor, and course developer; he currently works writing and creating certification tools. He is author of all the previous books in the Cisco Press CCNA Official Certification Guide series, as well as the *CCNP ROUTE 642-902 Official Certification Guide*, the *QoS 642-642 Exam Certification Guide*, coauthor of the *CCIE Routing and Switch Official Certification Guide*, and several other titles. He is also a consultant for the CCNA 640-802 Network Simulator from Pearson and for a forthcoming replacement version of that product. He maintains study tools, links to his blogs, and other resources at www.certskills.com.

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Elan Beer, CCIE No. 1837, is a senior consultant and Cisco instructor specializing in data center architecture and multiprotocol network design. For the past 25 years, Elan has designed networks and trained thousands of industry experts in data center architecture, routing, and switching. Elan has been instrumental in large-scale professional service efforts designing and troubleshooting internetworks, performing data center and network audits, and assisting clients with their short-and long-term design objectives. Elan has a global perspective of network architectures through his international clientele. Elan has used his expertise to design and troubleshoot data centers and internetworks in Malaysia, North America, Europe, Australia, Africa, China, and the Middle East. Most recently, Elan has been focused on data center design, configuration, and troubleshooting as well as service provider technologies. In 1993, Elan was among the first to obtain the Cisco Certified System Instructor (CCSI) certification, and in 1996, Elan was among the first to attain Cisco System’s highest technical certification, the Cisco Certified Internetworking Expert. Since then, Elan has been involved in numerous large-scale data center and telecommunications networking projects worldwide.

Dedication

In memory of William E. York: Mom’s dad, Paw Paw, wearing blue-jean overalls, always smiling, tagging along at the water works, fishing on Juliet Lake, the Catawba worm tree, and his big-belly laugh.

Acknowledgments

While this book is published as a first edition for various reasons, this book and the companion *Cisco CCNA Routing and Switching ICND2 200-101 Official Cert Guide* represent the seventh books in a long line of Cisco Press books focused on helping people pass the CCENT and CCNA Routing and Switching certifications. Given the long history, many people have worked on these books from their inception back in 1998. To those many people who have touched these books over these past 15 years—technical edits, development, copyedits, project editing, proofing, indexing, managing the production process, interior design, cover design, marketing, and all the other details that happen to get these books out the door—thanks so much for playing a role in this CCENT/CCNA franchise.

Many of the contributors to the previous editions returned to work on creating these new editions, including Development Editor Drew Cupp. Drew kept all the details straight, with my frequent changes to the outlines and titles, keeping the sequencing on track, while still doing his primary job: keeping the text and features clear and consistent throughout the book. Thanks, Drew, for walking me through the development.

As for the technical editor, Elan Beer did his normal job. That is, he did his usual amazing job of doing every part of the technical edit job well, from finding the tiny little cross-reference errors that sit pages apart, to anticipating how readers might misunderstand certain phrasing, to being all over the details of every technical feature. Fantastic job as usual—thanks, Elan.

Brett Bartow again served as Executive Editor on the book, as he has almost since the beginning of these titles. When my family has asked me over the years about Brett's role with these books, the best single word definition is "teammate." Brett might be employed at Pearson Education, but he is always working with me and for me, watching out for the business end of the books and finding ways to make the publisher/author relationship work seamlessly. Thanks for another great ride through these books, Brett!

Word docs go in and out come these beautiful finished products. Thanks to Sandra Schroeder, Tonya Simpson, and all the production team for working through the magic that takes those Word docs and makes the beautiful finished product. From fixing all my grammar, crummy word choices, and passive-voice sentences, and then pulling the design and layout together, they do it all—thanks for putting it all together and making it look easy. And Tonya, managing the details through several process steps for roughly 100 elements between the pair of CCNA books in a short time frame—thanks for the amazing juggling act! And thanks especially for the attention to detail.

The figures for these books go through a little different process than they do for other books. Together we invested a large amount of labor in updating the figures for these books, both for the design, the volume of figures, and for the color versions of the figures for the electronic versions of the books. A special thanks goes out to Laura Robbins for working with me on the color and design standards early in the process. Also, thanks to Mike Tanamachi for drawing all the figures so well—and then redrawing them every time I changed my mind about something.

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A special thanks you to you readers who write in with suggestions, possible errors, and especially those of you who post online at the Cisco Learning Network. Without question, the comments I receive directly and overhear by participating at CLN made this edition a better book.

Thanks to my wife, Kris. Book schedules have a bigger impact that I would like, but you always make it work. Thanks to my daughter, Hannah, for all the great study/work breaks on some of these busy school days. And thanks to Jesus Christ, for this opportunity to write.

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  - *IGP Routing Protocol Algorithms*
  - *Metrics*
  - *Other IGP Comparisons*
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  - Building the LSDB and Creating IP Routes
  - *Topology Information and LSAs*
  - *Applying Dijkstra SPF Math to Find the Best Routes*
  - Using OSPF Neighbor Relationships
  - *The Basics of OSPF Neighbors*
  - *Meeting Neighbors and Learning Their Router ID*
  - Scaling OSPF Through Hierarchical Design
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  - Exam-Day Advice
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  - Practice Subnetting and Other Math-Related Skills
  - Take Practice Exams
  - *Practicing Taking the ICND1 Exam*
  - *Practicing Taking the CCNA Exam*
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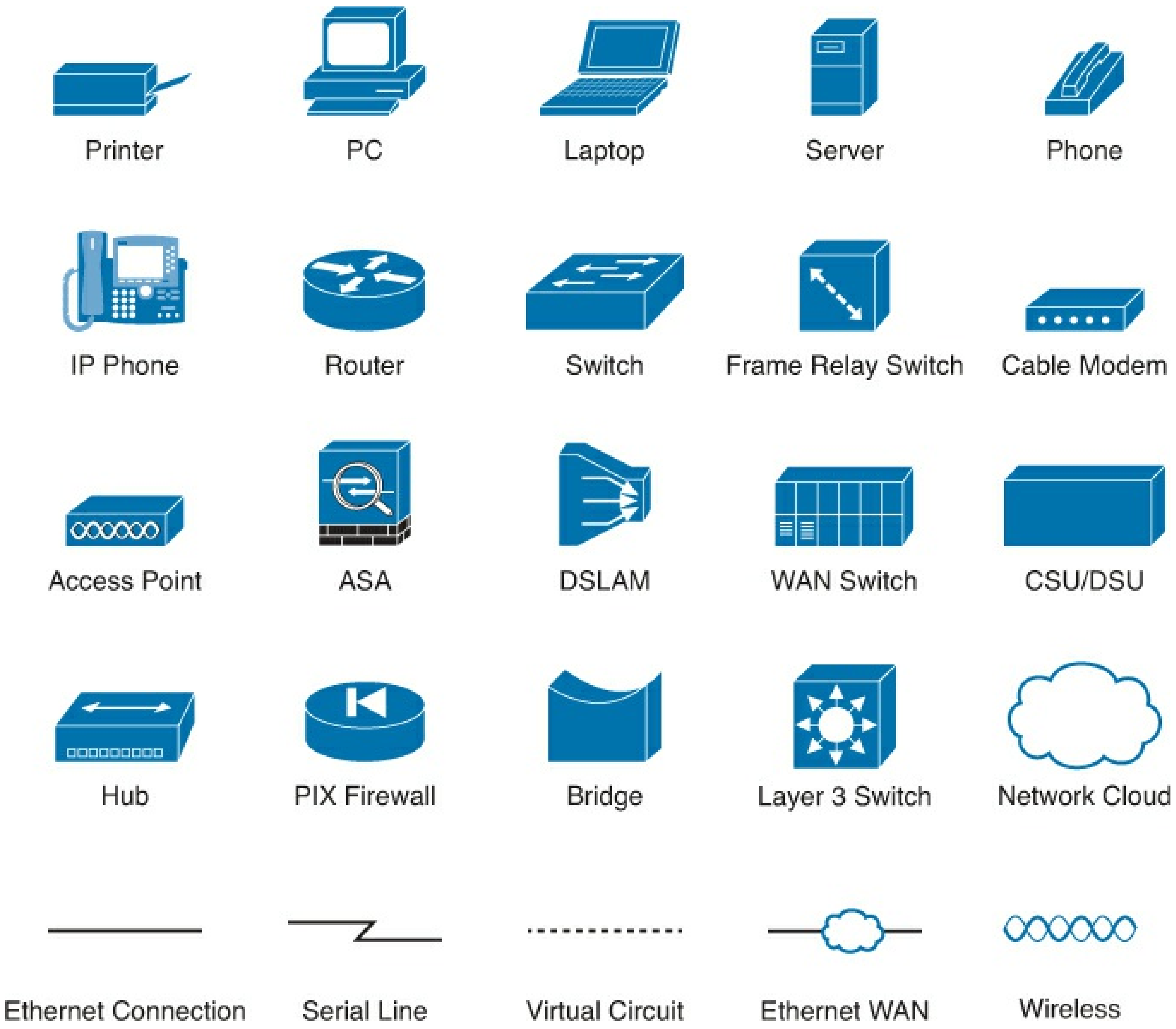
Appendix N: Memory Tables Answer Key

Appendix O: Mind Map Solutions

Appendix P: Study Planner

Where are the Companion Content Files?

Icons Used in This Book


Printer
PC
Laptop
Server
Phone
IP Phone
Router
Switch
Frame Relay Switch
Cable Modem
Access Point
ASA
DSLAM
WAN Switch
CSU/DSU
Hub
PIX Firewall
Bridge
Layer 3 Switch
Network Cloud
Ethernet Connection
Serial Line
Virtual Circuit
Ethernet WAN
Wireless

Command Syntax Conventions

The conventions used to present command syntax in this book are the same conventions used in the IOS Command Reference. The Command Reference describes these conventions as follows:

- **Boldface** indicates commands and keywords that are entered literally as shown. In actual configuration examples and output (not general command syntax), boldface indicates commands that are manually input by the user (such as a **show** command).
- *Italic* indicates arguments for which you supply actual values.
- Vertical bars (|) separate alternative, mutually exclusive elements.
- Square brackets ([ ]) indicate an optional element.
- Braces ({ }) indicate a required choice.
- Braces within brackets ([{ }]) indicate a required choice within an optional element.

Introduction

About the Exams

Congratulations! If you're reading far enough to look at this book's Introduction, you've probably already decided to go for your Cisco certification. If you want to succeed as a technical person in the networking industry, you need to know Cisco. Cisco has a ridiculously high market share in the router and switch marketplace, with more than an 80 percent share in some markets. In many geographies and markets around the world, networking equals Cisco. If you want to be taken seriously as a network engineer, Cisco certification makes perfect sense.

The Exams That Help You Achieve CCENT and CCNA

Cisco announced changes to the CCENT and CCNA Routing and Switching certifications, and the related 100-101 ICND1, 200-101 ICND2, and 200-120 CCNA exams, early in 2013. For those of you who understand the how the old Cisco ICND1, ICND2, and CCNA exams worked, the structure remains the same. For those of you new to Cisco certifications, this Introduction begins by discussing the basics.

Almost everyone new to Cisco certifications begins with either CCENT or CCNA Routing and Switching. CCENT certification requires knowledge and skills on about half as much material as does CCNA Routing and Switching, so CCENT is the easier first step.

The CCENT certification requires a single step: pass the ICND1 exam. Simple enough.

The CCNA Routing and Switching certification gives you two options, as show in Figure I-1: Pass both the ICND1 and ICND2 exams, or just pass the CCNA exam. (Note that there is no separate certification for passing the ICND2 exam.)

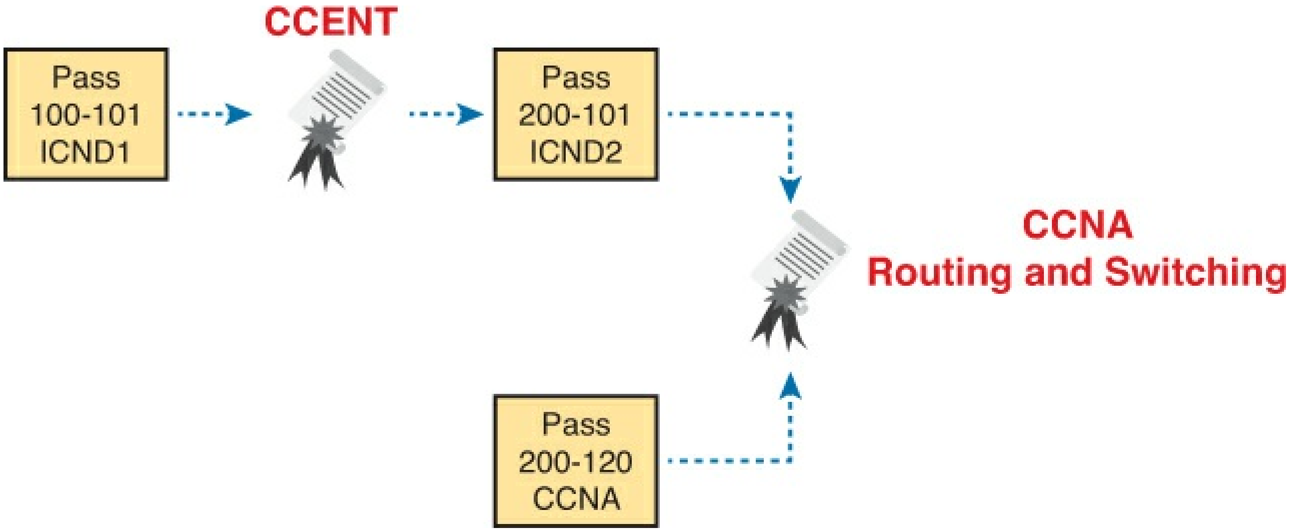


Figure I-1. Cisco Entry-Level Certifications and Exams

As you can see, although you can obtain the CCENT certification by taking the ICND1 exam, you do not have to be CCENT certified before you get your CCNA Routing and Switching certification. You can choose to take the CCNA exam and bypass the CCENT certification.

As for the topics themselves, the ICND1 and ICND2 exams cover different topics, but with some overlap required. For example, ICND1 covers the basics of the Open Shortest Path First (OSPF) routing protocol. ICND2 covers more detail about OSPF, but to discuss those additional details, ICND2 must rely on the parts of OSPF included in ICND1. Many topics in ICND2 build upon topics in ICND1, causing some overlap.

The CCNA exam covers all the topics in both ICND1 and ICND2—no more, no less.

Types of Questions on the Exams

The ICND1, ICND2, and CCNA exams all follow the same general format. At the testing center, you will sit in a quiet room with a PC. Before the exam timer begins, you will have a chance to do a few other tasks on the PC—for example, you can take a sample quiz just to get accustomed to the PC and the testing engine. Anyone who has user-level skills in getting around a PC should have no problems with the testing environment.

After the exam starts, the screen shows you question after question. The questions typically fall into one of the following categories:

- Multiple-choice (MC) single answer
- Multiple-choice (MC) multiple answer
- Testlet
- Drag-and-drop (DND)
- Simulated lab (Sim)

- Simlet

The first three items in the list are all actually multiple-choice questions. The multiple-choice format simply requires that you point and click a circle beside the correct answer(s). Cisco traditionally tells you how many answers you need to choose, and the testing software prevents you from choosing too many answers. The Testlet style gives you one larger scenario statement, with multiple different multichoice questions about that one scenario.

Drag-and-drop questions require you to move some items around on the GUI. You left-click and hold, move a button or icon to another area, and release the mouse button to place the object somewhere else—typically into a list. So, for some questions, to get the question correct, you might need to put a list of five things in the proper order.

The last two types both use a network simulator to ask questions. Interestingly, the two types actually allow Cisco to assess two very different skills. First, Sim questions generally describe a problem, and your task is to configure one or more routers and switches to fix the problem. The exam then grades the question based on the configuration you changed or added.

The Simlet questions might well be the most difficult style of question on the exams. Simlet questions also use a network simulator, but instead of answering the question by changing the configuration, the question includes one or more MC questions. The questions require that you use the simulator to examine the current behavior of a network, interpreting the output of any show commands that you can remember to answer the question. While Sim questions require you to troubleshoot problems related to a configuration, Simlets require you to both analyze both working and broken networks, correlating show command output with your knowledge of networking theory and configuration commands.

You can watch and even experiment with these command types using the Cisco Exam Tutorial. To find the Cisco Certification Exam Tutorial, go to www.cisco.com and search for "exam tutorial."

What's on the CCNA Exam(s)?

Ever since I was in grade school, whenever the teacher announced that we were having a test soon, someone would always ask, "What's on the test?" Even in college, people would try to get more information about what would be on the exams. At heart, the goal is to know what to study hard, what to study a little, and what to not study at all.

Cisco tells the world the topics on each of its exams. Cisco wants the public to know both the variety of topics, and an idea about the kinds of knowledge and skills required for each topic, for every Cisco certification exam. To that end, Cisco publishes a set of exam topics for each exam.

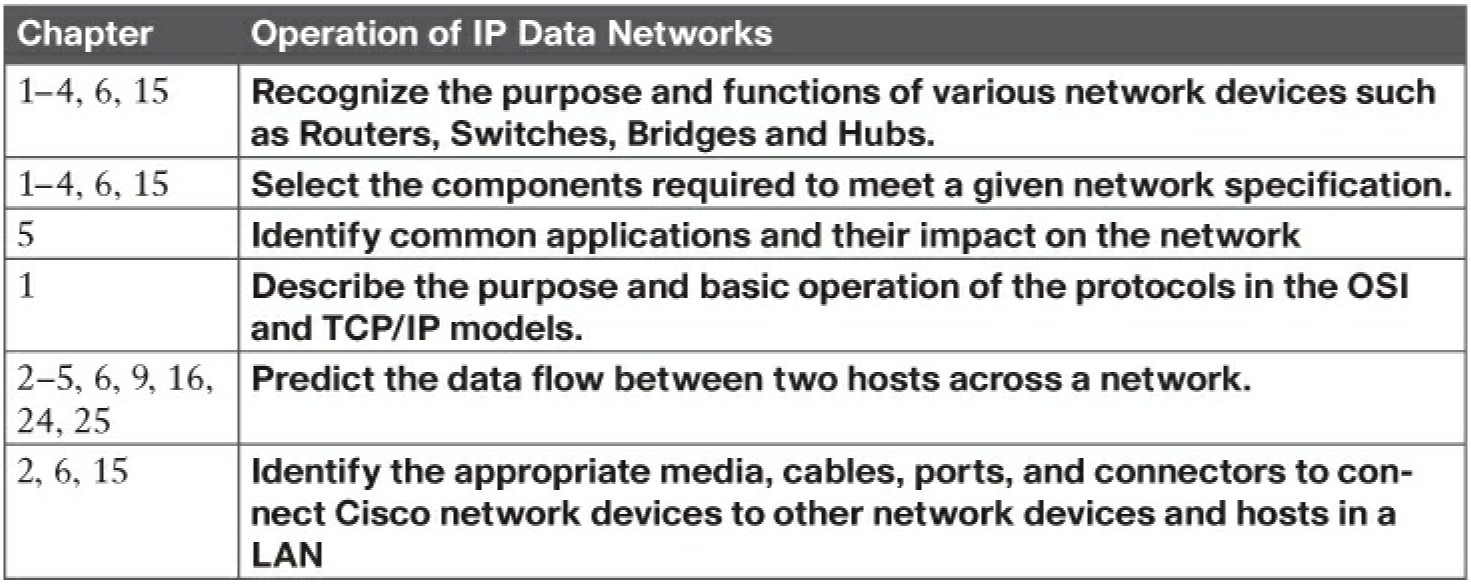
Many Cisco exam topics list both a networking topic and an important verb. The verb tells us to what degree the topic must be understood, and what skills are required. The topic also implies the kinds of skills required for that topic. For example, one topic might start with "Describe...," another with "Configure...," another with "Verify...," and another might begin with "Troubleshoot...." That last topic has the highest required skill level, because to troubleshoot, you must understand the topic, be able to configure it (to see what's wrong with the configuration), and verify it (to find the root cause of the problem). By listing the topics and skill level, Cisco helps us all prepare for its exams.

Although the exam topics are helpful, keep in mind that Cisco adds a disclaimer that the posted exam topics for all of its certification exams are guidelines. Cisco makes the effort to keep the exam questions within the confines of the stated exam topics, and I know from talking to those involved that every question is analyzed for whether it fits within the stated exam topics.

ICND1 Exam Topics

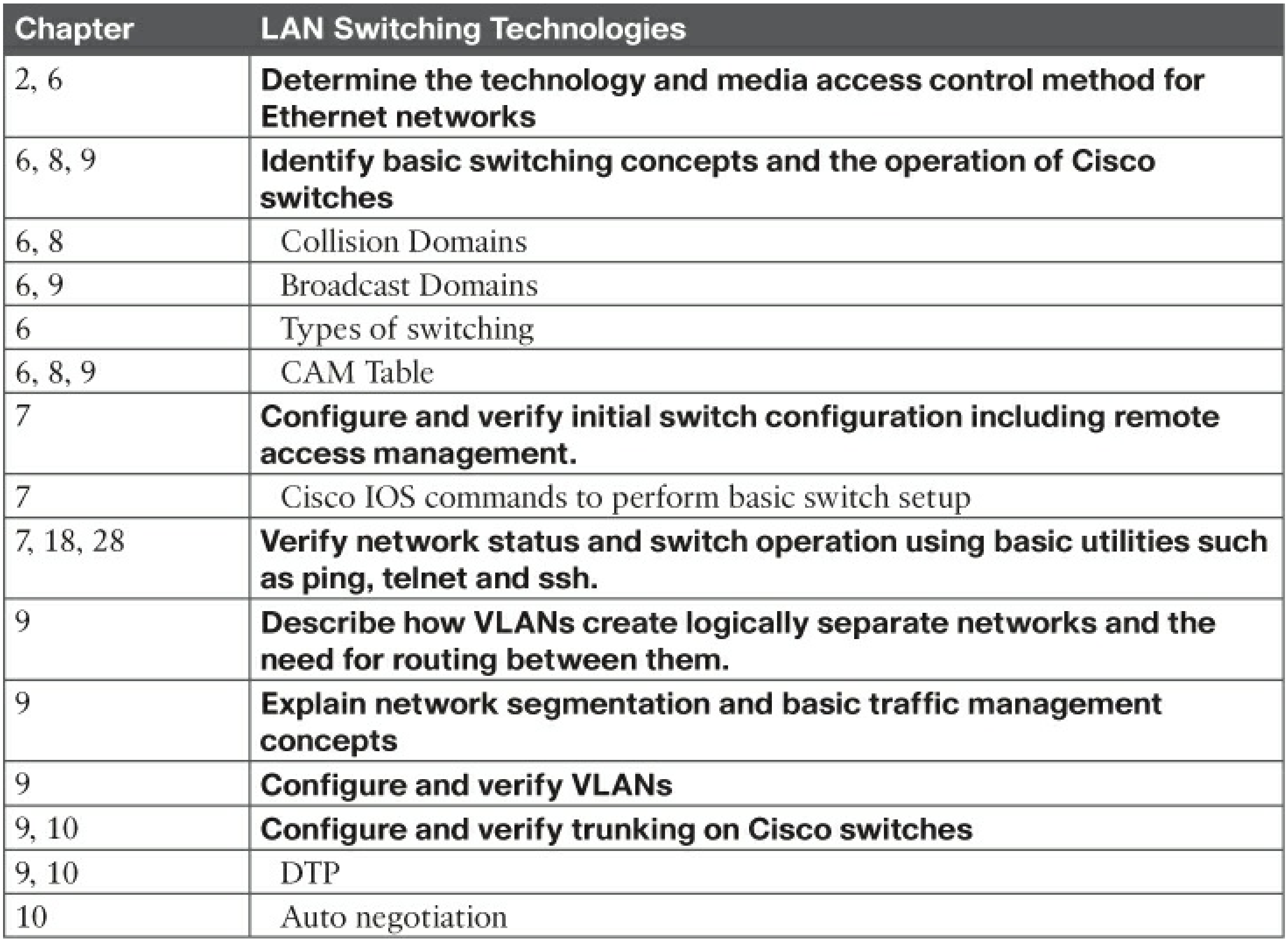
Tables I-1 through I-7 lists the exam topics for the ICND1 exam. Following those tables, Tables I-8 through I-12 list the exam topics for ICND2. These tables note the book chapters in which each exam topic is covered.

Table I-1. ICND1 Exam Topics: Operation of IP Data Networks



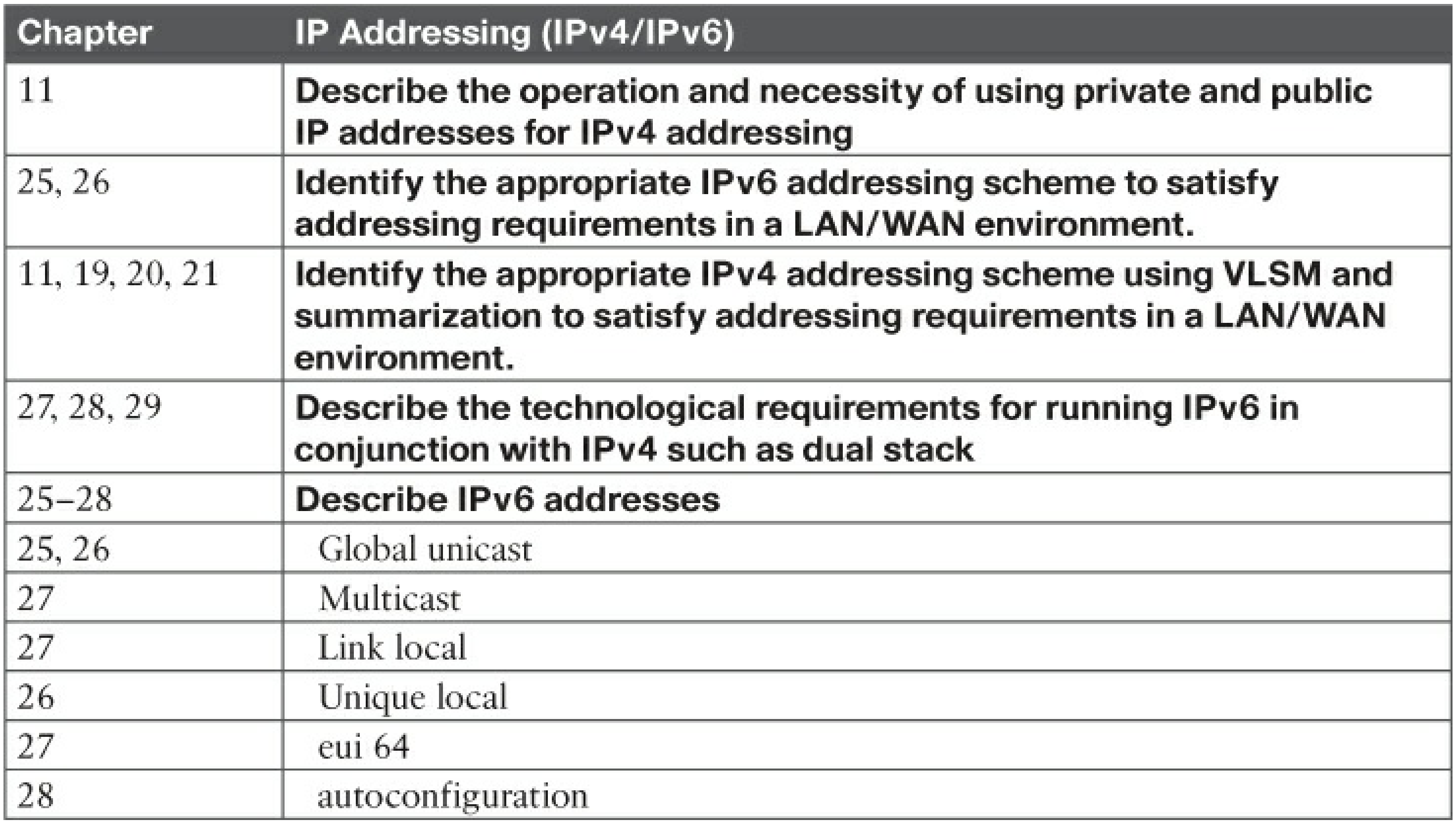
Chapter	Operation of IP Data Networks
1–4, 6, 15	Recognize the purpose and functions of various network devices such as Routers, Switches, Bridges and Hubs.
1–4, 6, 15	Select the components required to meet a given network specification.
5	Identify common applications and their impact on the network
1	Describe the purpose and basic operation of the protocols in the OSI and TCP/IP models.
2–5, 6, 9, 16, 24, 25	Predict the data flow between two hosts across a network.
2, 6, 15	Identify the appropriate media, cables, ports, and connectors to connect Cisco network devices to other network devices and hosts in a LAN

Table I-2. ICND1 Exam Topics: LAN Switching Technologies



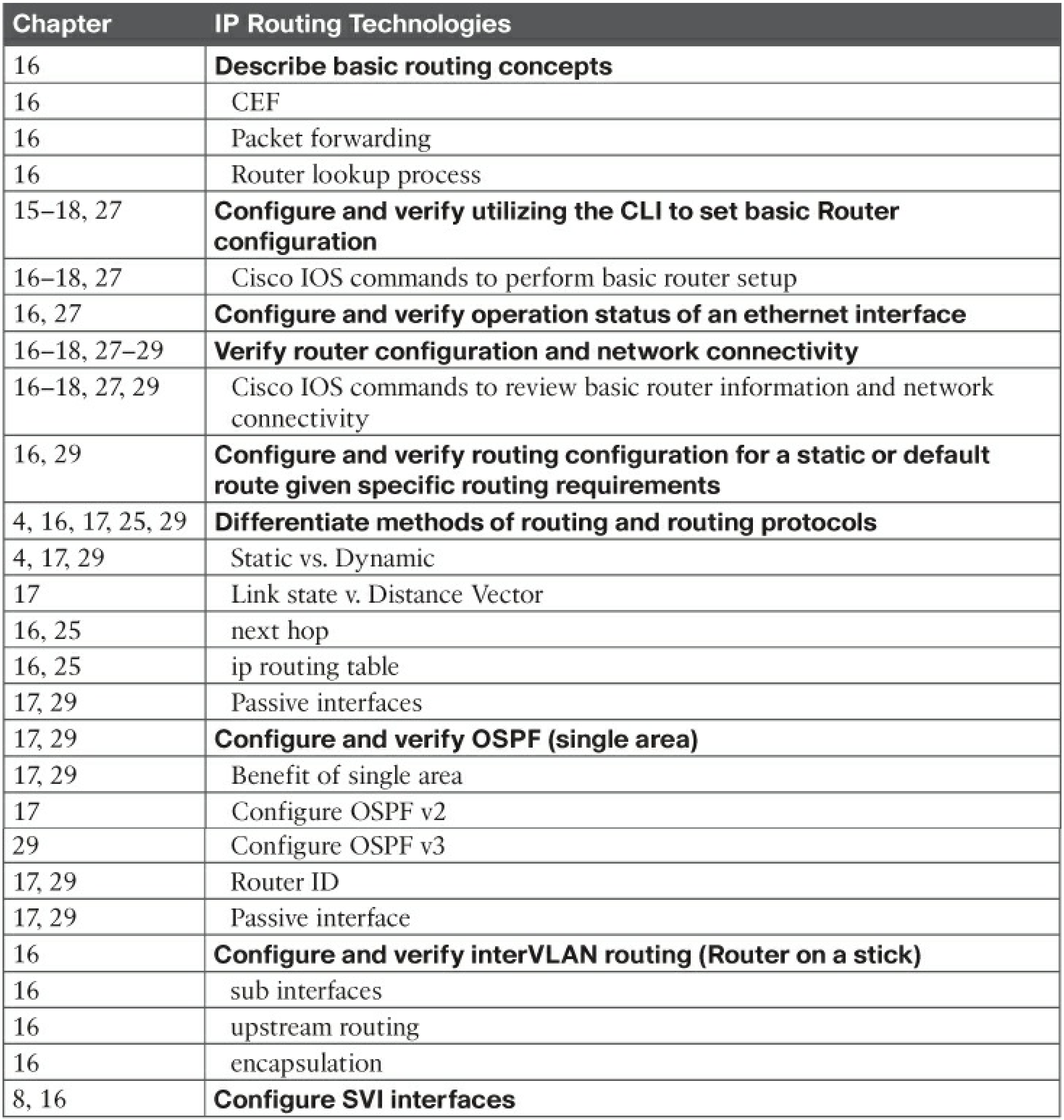
Chapter	LAN Switching Technologies
2, 6	**Determine the technology and media access control method for Ethernet networks**
6, 8, 9	**Identify basic switching concepts and the operation of Cisco switches**
6, 8	Collision Domains
6, 9	Broadcast Domains
6	Types of switching
6, 8, 9	CAM Table
7	**Configure and verify initial switch configuration including remote access management.**
7	Cisco IOS commands to perform basic switch setup
7, 18, 28	**Verify network status and switch operation using basic utilities such as ping, telnet and ssh.**
9	**Describe how VLANs create logically separate networks and the need for routing between them.**
9	**Explain network segmentation and basic traffic management concepts**
9	**Configure and verify VLANs**
9, 10	**Configure and verify trunking on Cisco switches**
9, 10	DTP
10	Auto negotiation

Table I-3. ICND1 Exam Topics: IP Addressing (IPv4 / IPv6)



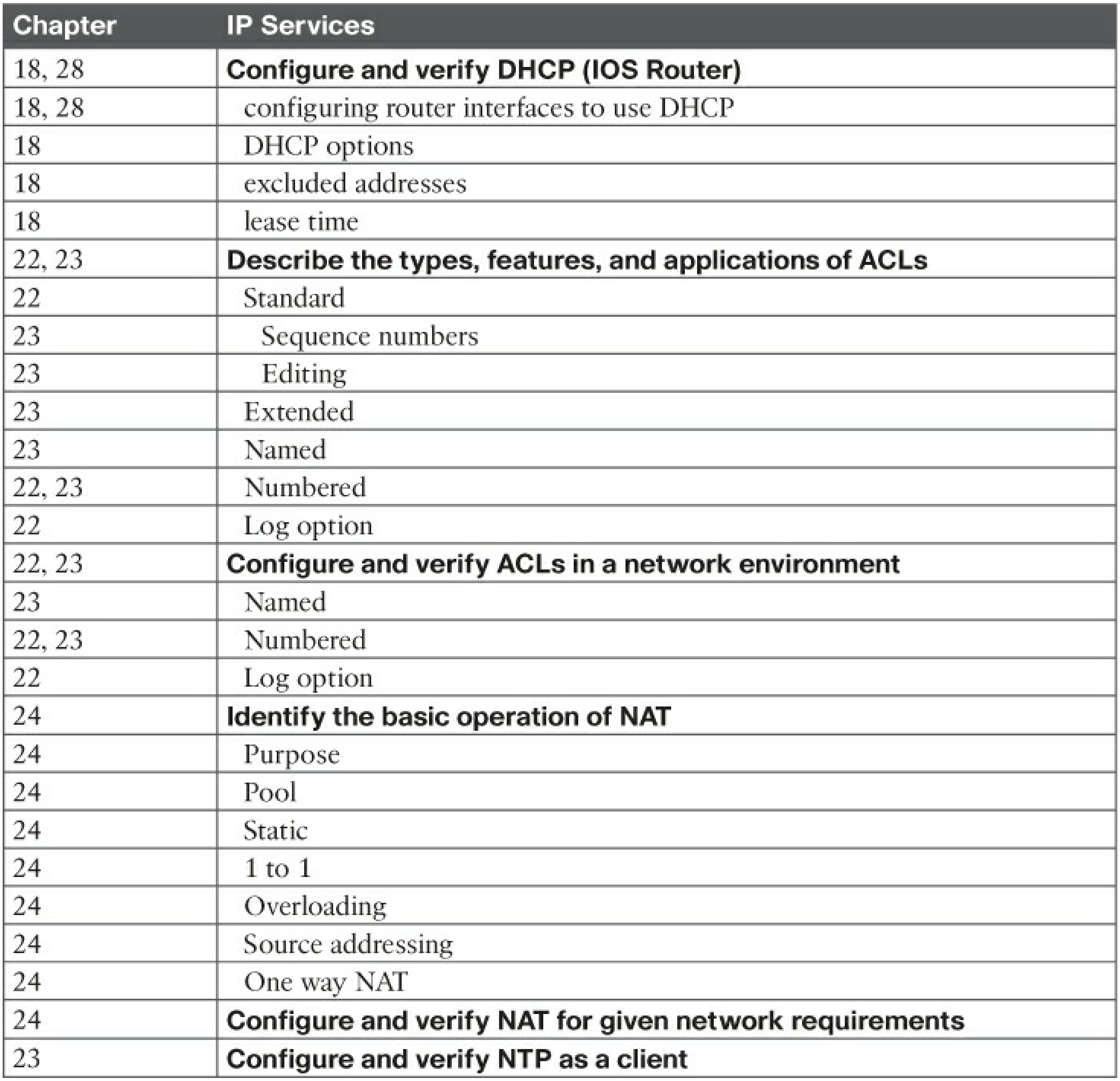
Chapter	IP Addressing (IPv4/IPv6)
11	**Describe the operation and necessity of using private and public IP addresses for IPv4 addressing**
25, 26	**Identify the appropriate IPv6 addressing scheme to satisfy addressing requirements in a LAN/WAN environment.**
11, 19, 20, 21	**Identify the appropriate IPv4 addressing scheme using VLSM and summarization to satisfy addressing requirements in a LAN/WAN environment.**
27, 28, 29	**Describe the technological requirements for running IPv6 in conjunction with IPv4 such as dual stack**
25–28	**Describe IPv6 addresses**
25, 26	Global unicast
27	Multicast
27	Link local
26	Unique local
27	eui 64
28	autoconfiguration

Table I-4. ICND1 Exam Topics: IP Routing Technologies



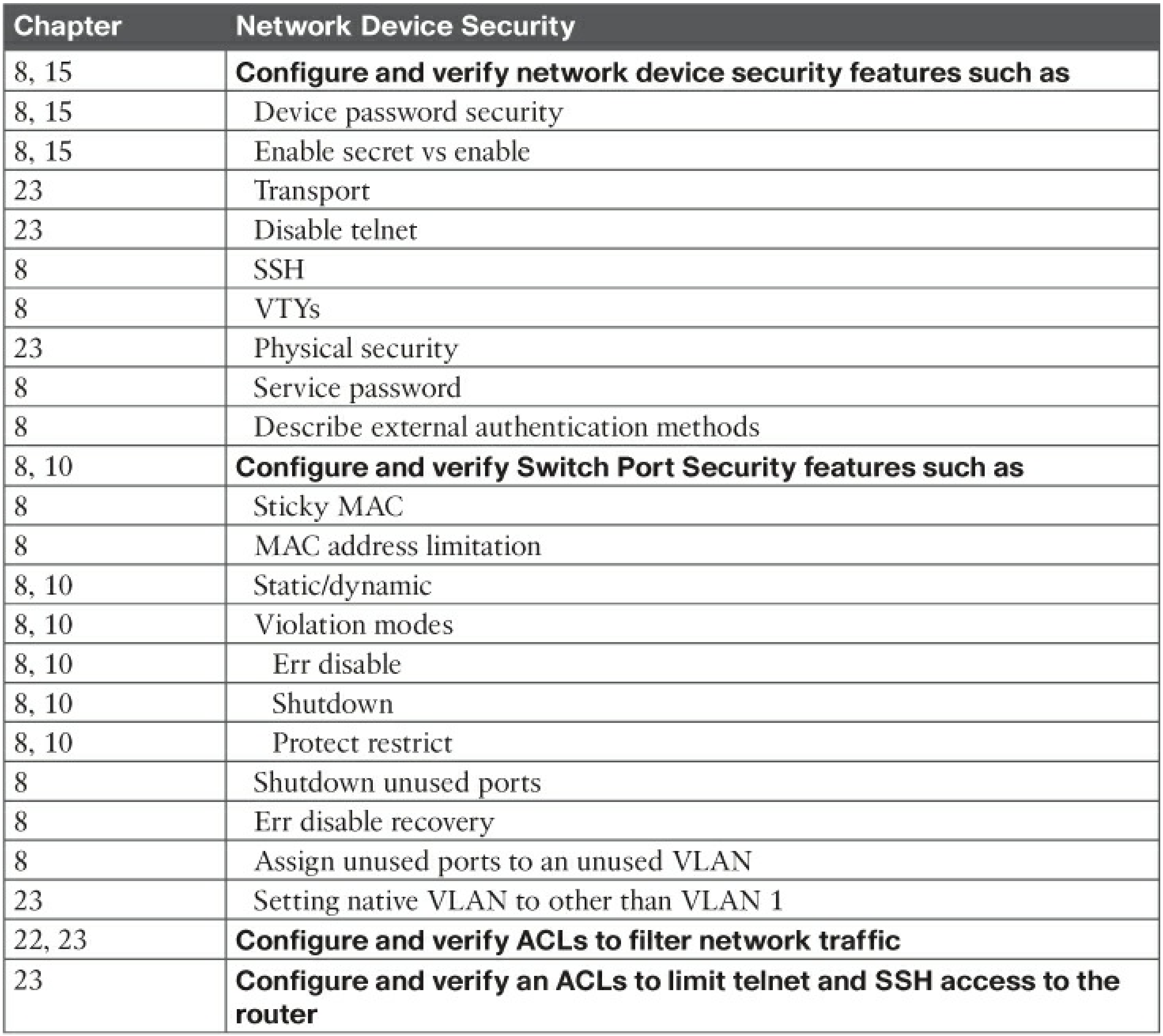
Chapter	IP Routing Technologies
16	**Describe basic routing concepts**
16	CEF
16	Packet forwarding
16	Router lookup process
15–18, 27	**Configure and verify utilizing the CLI to set basic Router configuration**
16–18, 27	Cisco IOS commands to perform basic router setup
16, 27	**Configure and verify operation status of an ethernet interface**
16–18, 27–29	**Verify router configuration and network connectivity**
16–18, 27, 29	Cisco IOS commands to review basic router information and network connectivity
16, 29	**Configure and verify routing configuration for a static or default route given specific routing requirements**
4, 16, 17, 25, 29	**Differentiate methods of routing and routing protocols**
4, 17, 29	Static vs. Dynamic
17	Link state v. Distance Vector
16, 25	next hop
16, 25	ip routing table
17, 29	Passive interfaces
17, 29	**Configure and verify OSPF (single area)**
17, 29	Benefit of single area
17	Configure OSPF v2
29	Configure OSPF v3
17, 29	Router ID
17, 29	Passive interface
16	**Configure and verify interVLAN routing (Router on a stick)**
16	sub interfaces
16	upstream routing
16	encapsulation
8, 16	**Configure SVI interfaces**

Table I-5. ICND1 Exam Topics: IP Services



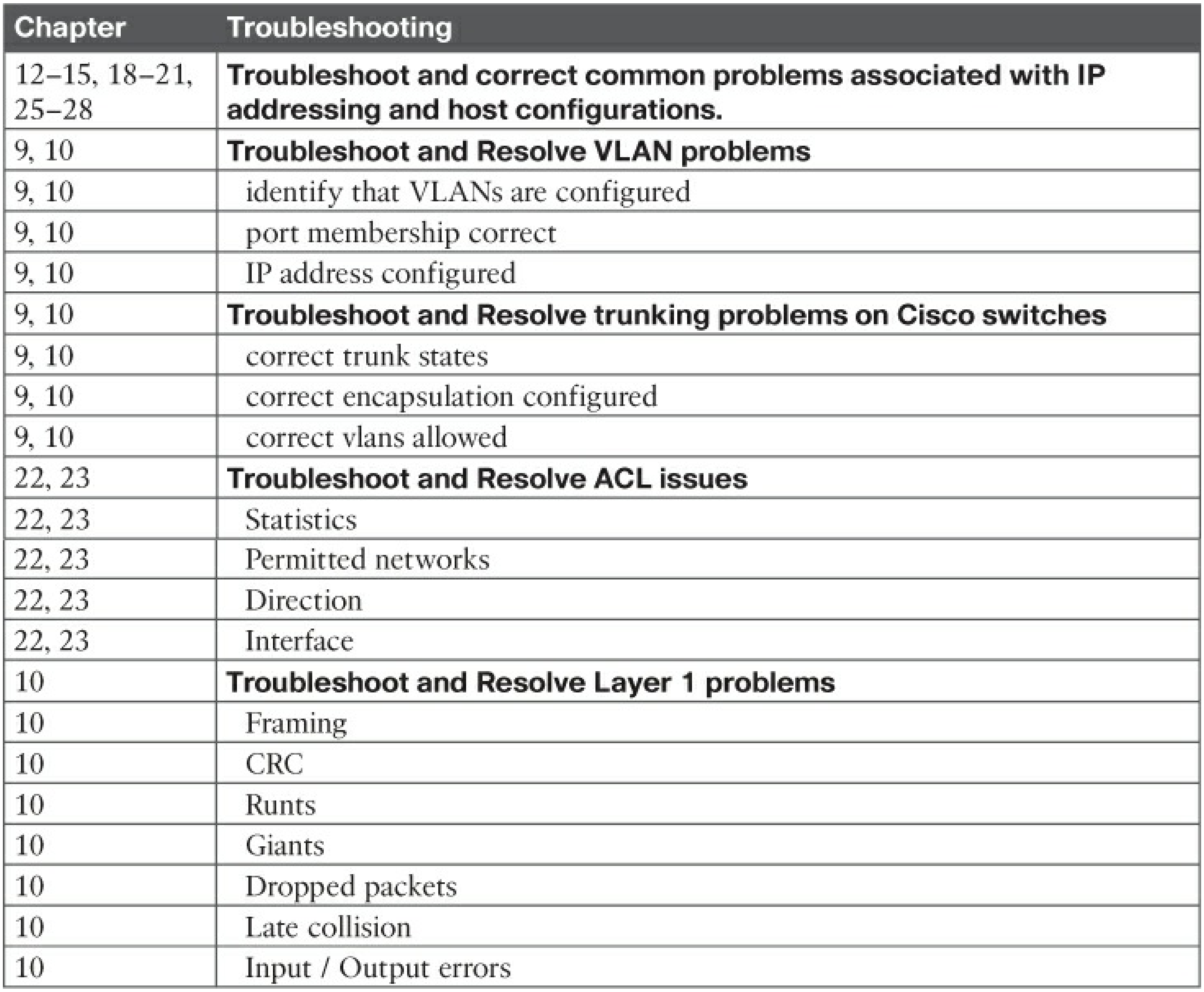
Chapter	IP Services
18, 28	**Configure and verify DHCP (IOS Router)**
18, 28	configuring router interfaces to use DHCP
18	DHCP options
18	excluded addresses
18	lease time
22, 23	**Describe the types, features, and applications of ACLs**
22	Standard
23	Sequence numbers
23	Editing
23	Extended
23	Named
22, 23	Numbered
22	Log option
22, 23	**Configure and verify ACLs in a network environment**
23	Named
22, 23	Numbered
22	Log option
24	**Identify the basic operation of NAT**
24	Purpose
24	Pool
24	Static
24	1 to 1
24	Overloading
24	Source addressing
24	One way NAT
24	**Configure and verify NAT for given network requirements**
23	**Configure and verify NTP as a client**

Table I-6. ICND1 Exam Topics: Network Device Security



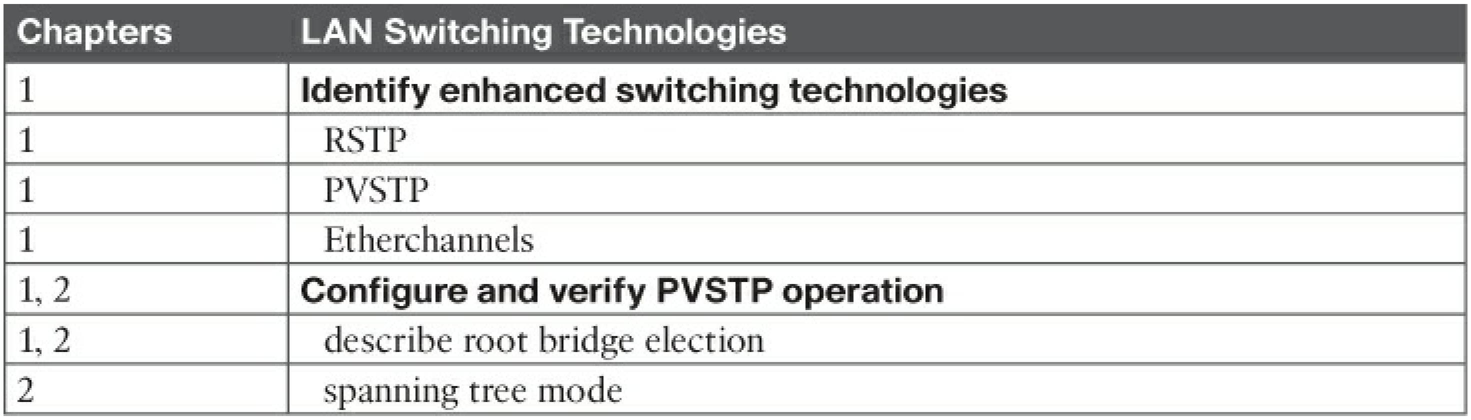
Chapter	Network Device Security
8, 15	**Configure and verify network device security features such as**
8, 15	Device password security
8, 15	Enable secret vs enable
23	Transport
23	Disable telnet
8	SSH
8	VTYs
23	Physical security
8	Service password
8	Describe external authentication methods
8, 10	**Configure and verify Switch Port Security features such as**
8	Sticky MAC
8	MAC address limitation
8, 10	Static/dynamic
8, 10	Violation modes
8, 10	Err disable
8, 10	Shutdown
8, 10	Protect restrict
8	Shutdown unused ports
8	Err disable recovery
8	Assign unused ports to an unused VLAN
23	Setting native VLAN to other than VLAN 1
22, 23	**Configure and verify ACLs to filter network traffic**
23	**Configure and verify an ACLs to limit telnet and SSH access to the router**

Table I-7. ICND1 Exam Topics: Troubleshooting



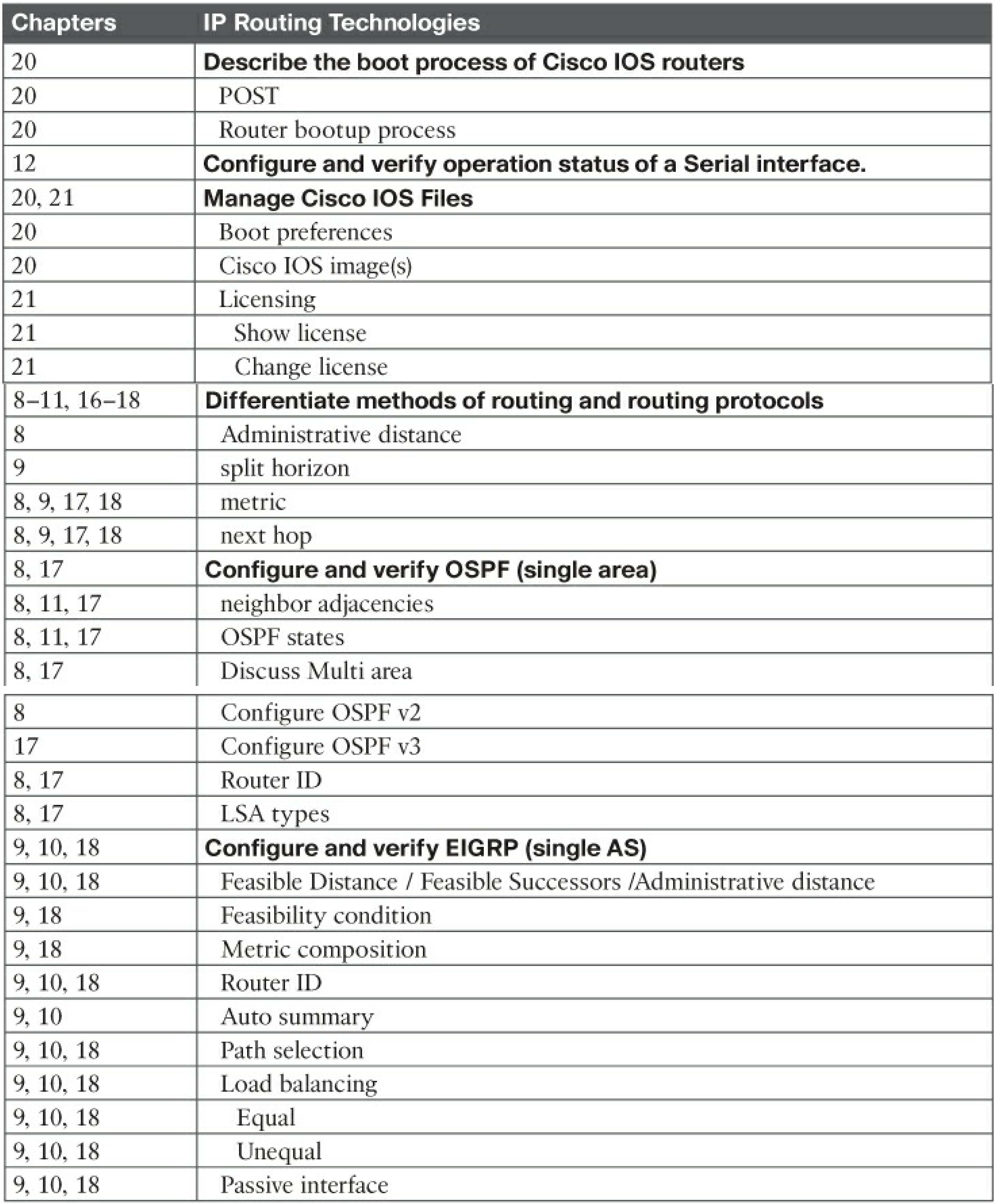
Chapter	Troubleshooting
12–15, 18–21, 25–28	**Troubleshoot and correct common problems associated with IP addressing and host configurations.**
9, 10	**Troubleshoot and Resolve VLAN problems**
9, 10	identify that VLANs are configured
9, 10	port membership correct
9, 10	IP address configured
9, 10	**Troubleshoot and Resolve trunking problems on Cisco switches**
9, 10	correct trunk states
9, 10	correct encapsulation configured
9, 10	correct vlans allowed
22, 23	**Troubleshoot and Resolve ACL issues**
22, 23	Statistics
22, 23	Permitted networks
22, 23	Direction
22, 23	Interface
10	**Troubleshoot and Resolve Layer 1 problems**
10	Framing
10	CRC
10	Runts
10	Giants
10	Dropped packets
10	Late collision
10	Input / Output errors

Table I-8. ICND2 Exam Topics: LAN Switching Technologies



Chapters	LAN Switching Technologies
1	**Identify enhanced switching technologies**
1	RSTP
1	PVSTP
1	Etherchannels
1, 2	**Configure and verify PVSTP operation**
1, 2	describe root bridge election
2	spanning tree mode

Table I-9. ICND2 Exam Topics, IP Routing Technologies



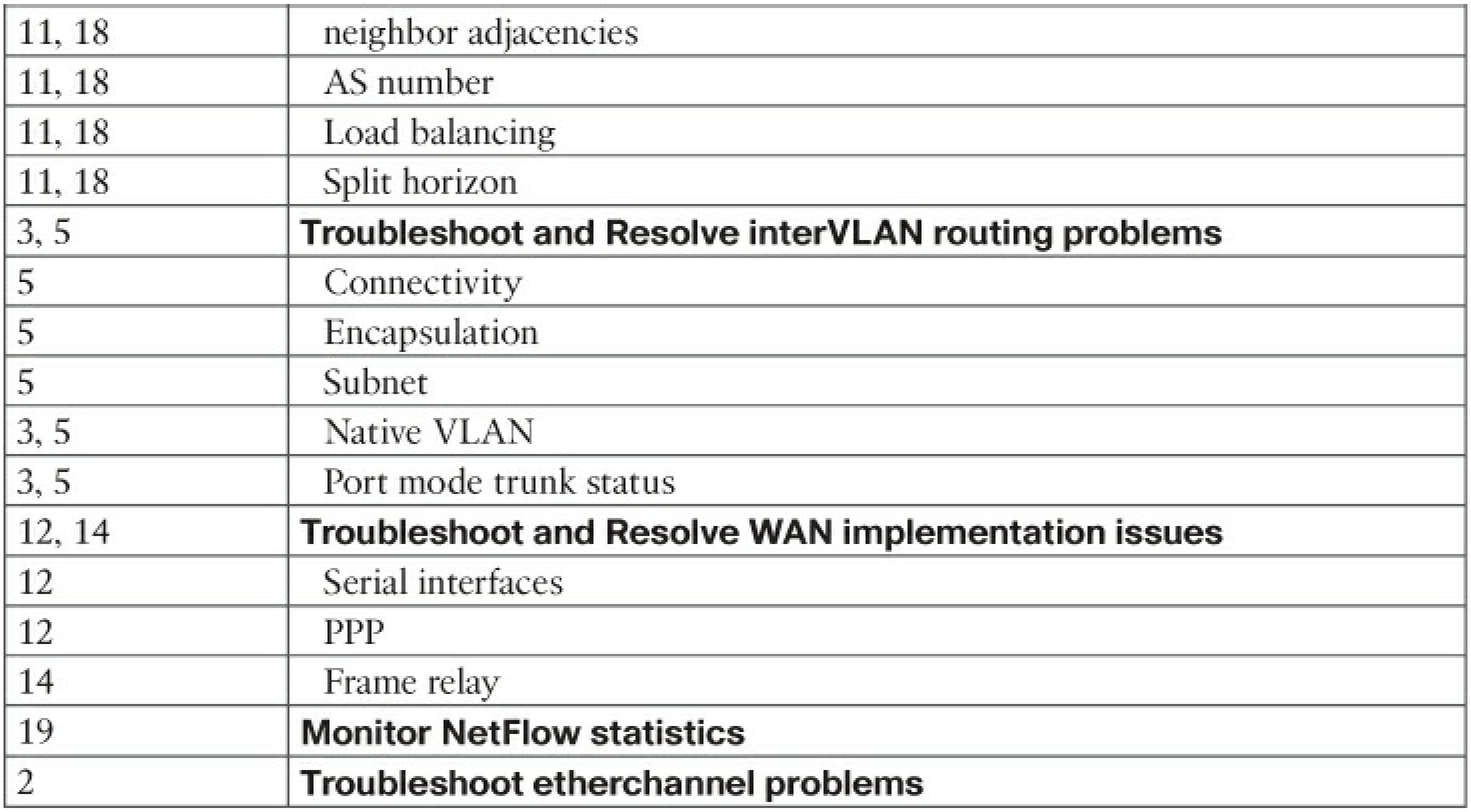
Chapters	IP Routing Technologies
20	**Describe the boot process of Cisco IOS routers**
20	POST
20	Router bootup process
12	**Configure and verify operation status of a Serial interface.**
20, 21	**Manage Cisco IOS Files**
20	Boot preferences
20	Cisco IOS image(s)
21	Licensing
21	Show license
21	Change license
8–11, 16–18	**Differentiate methods of routing and routing protocols**
8	Administrative distance
9	split horizon
8, 9, 17, 18	metric
8, 9, 17, 18	next hop
8, 17	**Configure and verify OSPF (single area)**
8, 11, 17	neighbor adjacencies
8, 11, 17	OSPF states
8, 17	Discuss Multi area
8	Configure OSPF v2
17	Configure OSPF v3
8, 17	Router ID
8, 17	LSA types
9, 10, 18	**Configure and verify EIGRP (single AS)**
9, 10, 18	Feasible Distance / Feasible Successors /Administrative distance
9, 18	Feasibility condition
9, 18	Metric composition
9, 10, 18	Router ID
9, 10	Auto summary
9, 10, 18	Path selection
9, 10, 18	Load balancing
9, 10, 18	Equal
9, 10, 18	Unequal
9, 10, 18	Passive interface

Table I-10. ICND2 Exam Topics, IP Services

Chapters	IP Services
6	**Recognize High availability (FHRP)**
6	VRRP
6	HSRP
6	GLBP
19	**Configure and verify Syslog**
19	Utilize Syslog Output
19	**Describe SNMP v2 & v3**

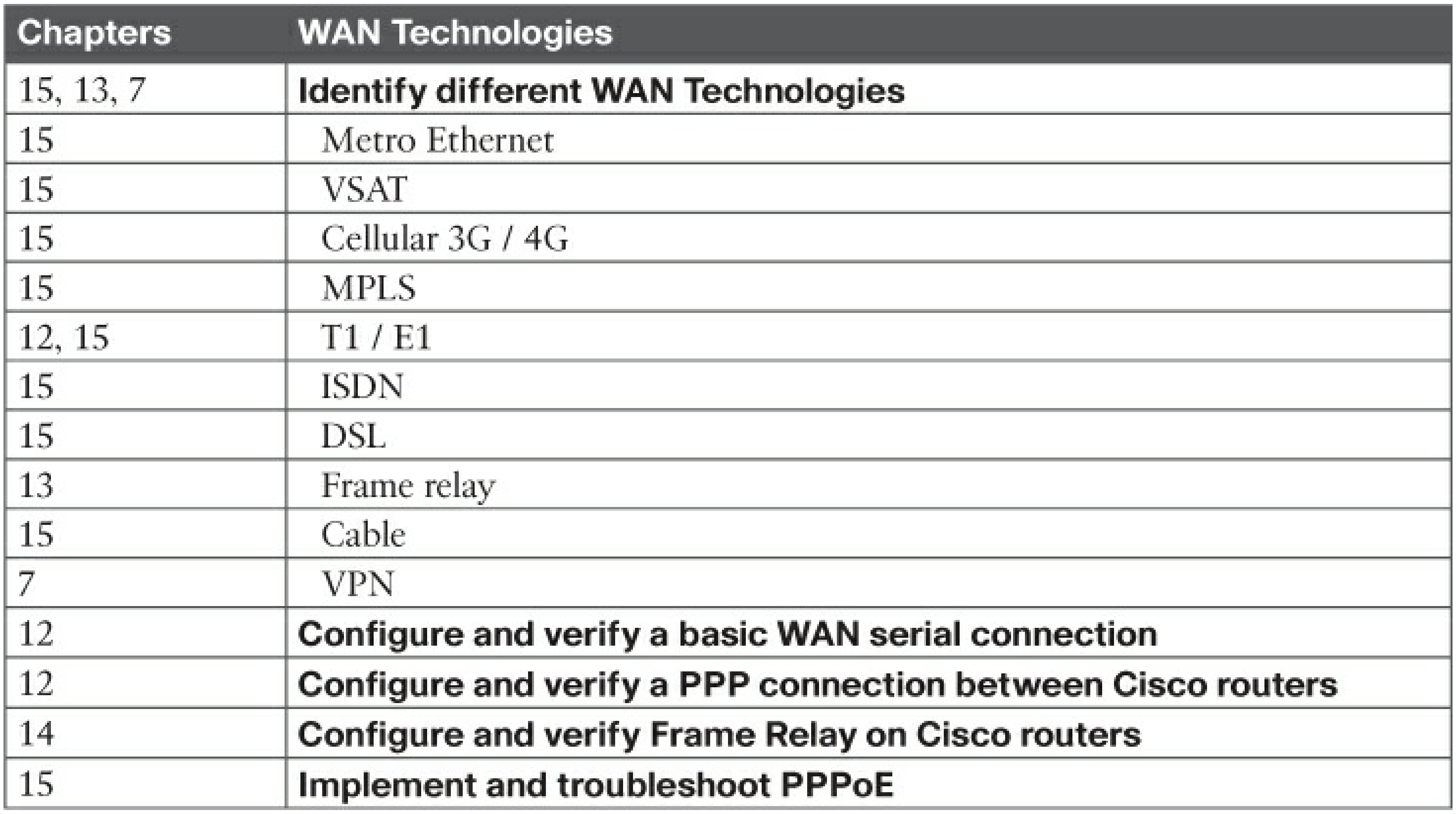
Table I-11. ICND2 Exam Topics, Troubleshooting

Chapters	Troubleshooting
3, 4, 5, 16	**Identify and correct common network problems**
19	**Utilize netflow data**
2	**Troubleshoot and Resolve Spanning Tree operation issues**
2	root switch
2	priority
2	mode is correct
2	port states
4, 5, 16	**Troubleshoot and Resolve routing issues**
4, 5, 16	routing is enabled
4, 5, 16	routing table is correct
4, 5, 16	correct path selection
11, 17	**Troubleshoot and Resolve OSPF problems**
11, 17	neighbor adjacencies
11, 17	Hello and Dead timers
11, 17	OSPF area
11, 17	Interface MTU
11, 17	Network types
11, 17	Neighbor states
11, 17	OSPF topology database
11, 18	**Troubleshoot and Resolve EIGRP problems**



11, 18	neighbor adjacencies
11, 18	AS number
11, 18	Load balancing
11, 18	Split horizon
3, 5	**Troubleshoot and Resolve interVLAN routing problems**
5	Connectivity
5	Encapsulation
5	Subnet
3, 5	Native VLAN
3, 5	Port mode trunk status
12, 14	**Troubleshoot and Resolve WAN implementation issues**
12	Serial interfaces
12	PPP
14	Frame relay
19	**Monitor NetFlow statistics**
2	**Troubleshoot etherchannel problems**

Table I-12. ICND2 Exam Topics: WAN Technologies



Chapters	WAN Technologies
15, 13, 7	**Identify different WAN Technologies**
15	Metro Ethernet
15	VSAT
15	Cellular 3G / 4G
15	MPLS
12, 15	T1 / E1
15	ISDN
15	DSL
13	Frame relay
15	Cable
7	VPN
12	**Configure and verify a basic WAN serial connection**
12	**Configure and verify a PPP connection between Cisco routers**
14	**Configure and verify Frame Relay on Cisco routers**
15	**Implement and troubleshoot PPPoE**

The tables follow the Cisco organization of topics, by both grouping similar topics and listing subtopics. The subtopics simply give more specific terms and concepts to provide more detail about some exam topics. The tables show the main topics with bold, and the subtopics as indented text inside the tables.

ICND2 Exam Topics

Tables I-8 through I-12 list the exam topics for ICND2. These tables note the book chapters in which each exam topic is covered in the ICND2 book. Note that each table covers a main exam topic. Cisco released further information on each topic to several sublevels of hierarchy. In this table, those sublevels are indented to indicate the topic above them that they are related to.

200-120 CCNA Exam Topics

The 200-120 CCNA exam actually covers everything from both the ICND1 and ICND2 exams, at least based on the published exam topics. As of this writing, the CCNA exam topics include all topics in Tables I-1 through I-12. In short, CCNA = ICND1 + ICND2.

> **Note**
>
> Because it is possible that the exam topics can change over time, it might be worth the time to double-check the exam topics as listed on the Cisco website (www.cisco.com/go/ccent and www.cisco.com/go/ccna). If Cisco does happen to add exam topics at a later date, note that Appendix B, "ICND1 Exam Updates," describes how to go to www.ciscopress.com and download additional information about those newly added topics.

About This Book

This book discusses the content and skills needed to pass the 100-101 ICND1 exam. That content also serves as basically the first half of the CCNA content, with this book's companion title, CCNA ICND2 200-101 Official Cert Guide, discussing the second half of the content.

Each of these books uses the same kinds of book features, so if you are reading both this book and the ICND2 book, there is no need to read the Introduction to the other book. Also, for those of you using both books to prepare for the 200-120 CCNA exam (rather than taking the two-exam option), the end of this Introduction lists a suggested reading plan.

Book Features

The most important and somewhat obvious objective of this book is to help you pass the ICND1 exam or the CCNA exam. In fact, if the primary objective of this book were different, the book's title would be misleading! However, the methods used in this book to help you pass the exams are also designed to make you much more knowledgeable about how to do your job.

This book uses several tools to help you discover your weak topic areas, to help you improve your knowledge and skills with those topics, and to prove that you have retained your knowledge of those topics. So, this book does not try to help you pass the exams only by memorization, but by truly learning and understanding the topics. The CCNA Routing and Switching certification is the foundation for many of the Cisco professional certifications, and it would be a disservice to you if this book did not help you truly learn the material. Therefore, this book helps you pass the CCNA exam by using the following methods:

- Helping you discover which exam topics you have not mastered
- Providing explanations and information to fill in your knowledge gaps
- Supplying exercises that enhance your ability to recall and deduce the answers to test questions
- Providing practice exercises on the topics and the testing process through test questions on the DVD

Chapter Features

To help you customize your study time using these books, the core chapters have several features that help you make the best use of your time:

- **"Do I Know This Already?" Quizzes:** Each chapter begins with a quiz that helps you determine the amount of time you need to spend studying that chapter.
- **Foundation Topics:** These are the core sections of each chapter. They explain the protocols, concepts, and configurations for the topics in that chapter.
- **Exam Preparation Tasks:** At the end of the "Foundation Topics" section of each chapter, the "Exam Preparation Tasks" section lists a series of study activities that should be done at the end of the chapter. Each chapter includes the activities that make the most sense for studying the topics in that chapter. The activities include the following:
  - **Review Key Topics:** The Key Topic icon is shown next to the most important items in the "Foundation Topics" section of the chapter. The Key Topics Review activity lists the key topics from the chapter and their corresponding page numbers. Although the contents of the entire chapter could be on the exam, you should definitely know the information listed in each key topic.
  - **Complete Tables and Lists from Memory:** To help you exercise your memory and memorize some lists of facts, many of the more important lists and tables from the chapter are included in a document on the DVD. This document lists only partial information, allowing you to complete the table or list.
  - **Define Key Terms:** Although the exams are unlikely to ask a question like, "Define this term," the CCNA exams require that you learn and know a lot of networking terminology. This section lists the most important terms from the chapter, asking you to write a short definition and compare your answer to the Glossary at the end of this book.
  - **Command Reference Tables:** Some book chapters cover a large amount of configuration and EXEC commands. These tables list the commands introduced in the chapter, along with an explanation. For exam preparation, use it for reference, but also read the table once when performing the Exam Preparation Tasks to make sure that you remember what all the commands do.

Part Review

The Part Review tasks help you prepare to apply all the concepts in this part of the book. (Each book part contains a number of related chapters.) The part review includes sample test questions, which require you to apply the concepts from multiple chapters in that part, uncovering what you truly understood and what you did not quite yet understand. The part review also uses mind map exercises that help you mentally connect concepts, configuration, and verification, so that no matter what perspective a single exam question takes, you can analyze and answer the question.

The part reviews list tasks, along with checklists so that you can track your progress. The following list explains the most common tasks you will see in the Part Review sections; note that not all Part Review sections use every type of task:

- **Review DIKTA Questions:** Although you have already seen the DIKTA questions from the chapters in a part, reanswering those questions can be a useful way to review facts. The Part Review section suggests that you repeat the DIKTA questions, but using the PCPT exam software that comes with the book, for extra practice in answering multichoice questions on a computer.
- **Answer Part Review Questions:** The PCPT exam software includes several exam databases. One exam database holds Part Review questions, written specifically for Part Review. These questions purposefully include multiple concepts in each question, sometimes from multiple chapters, to help build the skills needed for the more challenging analysis questions on the exams.
- **Review Key Topics:** Yes, again! They are indeed the most important topics in each chapter.
- **Create Configuration Mind Maps:** Mind maps are graphical organizing tools that many people find useful when learning and processing how concepts fit together. The process of creating mind maps helps you build mental connections between concepts and configuration commands, as well as develop your recall of the individual commands. For this task, you can create the mind map on paper or using any mind-mapping or graphic organizer software. (For more information on mind maps, refer to this book's Introduction, in the section "About Mind Maps.")
- **Create Verification Mind Maps:** These mind-mapping exercises focus on helping you connect router and switch show commands to either networking concepts or to configuration commands. Simply create the mind maps on paper or use any mind-mapping or graphic organizer software.
- **Repeat Chapter Review Tasks:** (Optional) Browse through the Chapter Review tasks, and repeat any Chapter Review tasks that you think might help you with review at this point.

Final Prep Tasks

Chapter 30, "Final Review," near the end of this book, lists a series of preparation tasks that you can best use for your final preparation before taking the exam.

Other Features

In addition to the features in each of the core chapters, this book, as a whole, has additional study resources, including

- **DVD-based practice exam:** The companion DVD contains the powerful Pearson IT Certification Practice Test exam engine. You can take simulated ICND1 exams, as well as simulated CCNA exams, with the DVD and activation code included in this book. (You can take simulated ICND2 and CCNA exams with the DVD in the *Cisco CCNA Routing and Switching ICND2 200-101 Official Cert Guide*.)
- **CENT/CCNA ICND1 Simulator Lite:** This lite version of the best-selling CCNA Network Simulator from Pearson provides you with a means, right now, to experience the Cisco command-line interface (CLI). There's no need to go buy real gear or buy a full simulator to start learning the CLI. Just install it from the DVD in the back of this book.
- **eBook:** If you are interested in obtaining an eBook version of this title, we have included a special offer on a coupon card inserted in the DVD sleeve in the back of the book. This offer allows you to purchase the *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide* Premium Edition eBook and Practice Test at a 70 percent discount off the list price. In addition to three versions of the eBook—PDF (for reading on your computer), EPUB (for reading on your tablet, mobile device, or Nook or other eReader), and Mobi (the native Kindle version)—you will also receive additional practice test questions and enhanced practice test features.
- **Subnetting videos:** The companion DVD contains a series of videos that show you how to calculate various facts about IP addressing and subnetting (in particular, using the shortcuts described in this book).
- **Subnetting practice:** The companion DVD contains five appendices (D through H), and each appendix contains a set of IPv4 subnetting practice problems, with the answers, and with explanations of how the answers were found. This is a great resource to get ready to do subnetting well and fast.
- **Other practice:** The companion DVD contains four other appendices (I through L) that each contain other practice problems related to a particular chapter from the book. Use these for more practice on the particulars with some of the math-and process-oriented activities in the chapters.
- **Mentoring videos:** The DVD included with this book includes four other instructional videos, about the following topics: Switch Basics, CLI Navigation, Router Configuration, and VLANs.
- **Companion website:** The website www.ciscopress.com/title/9781587143854 posts up-to-the-minute materials that further clarify complex exam topics. Check this site regularly for new and updated postings written by the author that provide further insight into the more troublesome topics on the exam.
- **PearsonITCertification.com:** The www.pearsonitcertification.com website is a great resource for all things ITcertification related. Check out the great CCNA Routing and Switching articles, videos, blogs, and other certification preparation tools from the industry's best authors and trainers.
- **CCNA Simulator:** If you are looking for more hands-on practice, you might want to consider purchasing the CCNA Network Simulator. You can purchase a copy of this software from Pearson at http://pearsonitcertification.com/networksimulator or from other retail outlets. To help you with your studies, I have created a mapping guide that maps each of the labs in the simulator to the specific sections in these CCNA Cert Guides.

You can get this mapping guide for free on the “Extras” tab of the companion website.

- **Author’s website and blogs:** The author maintains a website that hosts tools and links useful when studying for CCENT and CCNA Routing and Switching. The site lists information to help you build your own lab, study pages that correspond to each chapter of this book and the ICND2 book, and links to the author’s CCENT Skills blog and CCNA Skills blog. Start at www.certskills.com; check the tabs for study and blogs in particular.

Book Organization, Chapters, and Appendices

This book contains 29 core chapters, Chapters 1 through 29, with Chapter 30 including some suggestions for how to approach the actual exams. Each core chapter covers a subset of the topics on the ICND1 exam. The core chapters are organized into sections. The core chapters cover the following topics:

Part I: Networking Fundamentals

- **Chapter 1, “The TCP/IP and OSI Networking Models,”** introduces the terminology surrounding two different networking architectures, namely Transmission Control Protocol/Internet Protocol (TCP/IP) and Open Systems Interconnection (OSI).
- **Chapter 2, “Fundamental of Ethernet LANs,”** covers the concepts and terms used for the most popular option for the data link layer for local-area networks (LAN), namely Ethernet.
- **Chapter 3, “Fundamentals of WANs,”** covers the concepts and terms used for the most popular options for the data link layer for wide-area networks (WAN), including High-Level Data Link Control (HDLC).
- **Chapter 4, “Fundamentals of IPv4 Addressing and Routing”:** The Internet Protocol (IP) is the main network layer protocol for TCP/IP. This chapter introduces the basics of IP version 4 (IPv4), including IPv4 addressing and routing.
- **Chapter 5, “Fundamentals of TCP/IP Transport and Applications”:** The Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) are the main transport layer protocols for TCP/IP. This chapter introduces the basics of TCP and UDP.

Part II: Ethernet LANs and Switches

- **Chapter 6, “Building Ethernet LANs with Switches,”** deepens and expands the introduction to LANs from Chapter 2, discussing the roles and functions of LAN switches.
- **Chapter 7, “Installing and Operating Cisco LAN Switches,”** explains how to access, examine, and configure Cisco Catalyst LAN switches.
- **Chapter 8, “Configuring Ethernet Switching,”** shows how to configure a variety of switch features, including duplex and speed, port security, securing the CLI, and the switch IP address.
- **Chapter 9, “Implementing Ethernet Virtual LANs”:** This chapter explains the concepts and configuration surrounding virtual LANs, including VLAN trunking and the VLAN Trunking Protocol.
- **Chapter 10, “Troubleshooting Ethernet LANs,”** focuses on how to tell whether the switch is doing what it is supposed to be doing, mainly through the use of show commands.

Part III: IP Version 4 Addressing and Subnetting

- **Chapter 11, “Perspectives on IPv4 Subnetting,”** walks you through the entire concept of subnetting, from starting with a Class A, B, or C network; analyzing requirements; making choices; calculating the resulting subnets; and assigning those on paper, all in preparation to deploy and use those subnets by configuring the devices.
- **Chapter 12, “Analyzing Classful IPv4 Networks”:** IPv4 addresses originally fell into several classes, with unicast IP addresses being in Class A, B, and C. This chapter explores all things related to address classes and the IP network concept created by those classes.
- **Chapter 13, “Analyzing Subnet Masks”:** In most jobs, someone else came before you and chose the subnet mask used in a network. What does that mean? What does that mask do for you? This chapter focuses on how to look at the mask (and IP network) to discover key facts, like the size of a subnet (number of hosts) and the number of subnets in the network.
- **Chapter 14, “Analyzing Existing Subnets”:** Most troubleshooting of IP connectivity problems starts with an IP address and mask. This chapter takes that paired information and shows you how to find and analyze the subnet in which that IP address resides, including finding the subnet ID, range of addresses in the subnet, and subnet broadcast address.

Part IV: Implementing IP Version 4

- **Chapter 15, “Operating Cisco Routers,”** is like Chapter 8, but it focuses on routers instead of switches.
- **Chapter 16, “Configuring IPv4 Addresses and Routes,”** discusses how to add IPv4 address configuration to router interfaces, the routes that the router creates as a result, and how to configure static IPv4 routes.
- **Chapter 17, “Learning IPv4 Routes with OSPFv2,”** explains how routers work together to find all the best routes to each subnet using a routing protocol. This chapter also shows how to configure the OSPF routing protocol for use with IPv4.
- **Chapter 18, “Configuring and Verifying Host Connectivity,”** discusses several tools useful when working with IPv4 configuration on hosts. In particular, this chapter discusses DHCP, ping, and traceroute and how to configure IPv4 settings on a host.

Part V: Advanced IPv4 Addressing Concepts

- **Chapter 19, “Subnet Design,”** reverses the approach to IPv4 subnetting as compared to Part III of this book. Instead, this chapter consider questions about why a particular mask might be chosen, and if chosen, what subnet IDs exist.
- **Chapter 20, “Variable-Length Subnet Masks,”** takes IPv4 subnetting to another challenge level, in which different

subnets in the same network can use a different subnet mask so that the subnets in the same network have different sizes.

- **Chapter 21**, "**Route Summarization**," looks at a process that can be configured for routing protocols so that the protocol advertises one route, for a larger set of addresses, rather than many routes, each for a smaller set of addresses.

Part VI: **IPv4 Services**

- **Chapter 22**, "**Basic IPv4 Access Control Lists**": This chapter examines how standard IP ACLs can filter packets based on the source IP address so that a router will not forward the packet.
- **Chapter 23**, "**Advanced IPv4 ACLs and Device Security**": This chapter examines both named and numbered ACLs, with emphasis on how extended IP ACLs can match packets based on both source and destination IP address, and by matching source and destination TCP and UDP port numbers.
- **Chapter 24**, "**Network Address Translation**": This chapter closely examines the concepts behind the depletion of the IPv4 address space, and how NAT, in particular the Port Address Translation (PAT) option, helps solve the problem. The chapter also shows how to configure NAT on routers using the IOS CLI.

Part VII: **IP Version 6**

- **Chapter 25**, "**Fundamentals of IP Version 6**," discusses the most basic concepts of IP version 6, focusing on the rules for writing and interpreting IPv6 addresses.
- **Chapter 26**, "**IPv6 Addressing and Subnetting**," works through the two branches of unicast IPv6 addresses—global unicast addresses and unique local addresses—that act somewhat like IPv4 public and private addresses, respectively. This chapter also shows how IPv6 implements subnetting.
- **Chapter 27**, "**Implementing IPv6 Addressing on Routers**," shows how to configure IPv6 routing and addresses on routers. It also shows the link-local unicast address, plus other special addresses used by routers.
- **Chapter 28**, "**Implementing IPv6 Addressing on Hosts**," shows how to add IPv6 configuration on hosts, with emphasis on the two methods by which hosts can learn IPv6 settings: stateful DHCPv6 and Stateless Address Autoconfiguration (SLAAC).
- **Chapter 29**, "**Implementing IPv6 Routing**," shows how to adds routes to an IPv6 router's routing table, both through static configuration and with OSPF version 3 (OSPFv3).

Part VIII: **Final Preparation**

- **Chapter 30**, "**Final Review**," suggests a plan for final preparation after you have finished the core parts of the book, in particular explaining the many study options available in the book.

Part IX: **Appendices** **(In Print)**

- **Appendix A**, "**Numeric Reference Tables**," lists several tables of numeric information, including a binary-to-decimal conversion table and a list of powers of 2.
- **Appendix B**, "**ICND1 Exam Updates**," covers a variety of short topics that either clarify or expand upon topics covered earlier in the book. This appendix is updated from time to time, and posted at www.ciscopress.com/title/1587143852, with the most recent version available at the time of printing included here as Appendix B. (The first page of the appendix includes instructions on how to check to see whether a later version of Appendix B is available online.)
- The **Glossary** contains definitions for all the terms listed in the "Definitions of Key Terms" sections at the conclusion of Chapters 1 through 29.

Appendixes (on the DVD)

The following appendices are available in digital format on the DVD that accompanies this book:

- **Appendix C**, "**Answers to the 'Do I Know This Already?' Quizzes**," includes the explanations to all the questions from Chapters 1 through 29.
- **Appendix D**, "**Practice for Chapter 12: Analyzing Classful IPv4 Networks**," lists practice problems associated with Chapter 12. In particular, the practice questions ask you to find the classful network number in which an address resides, and all other facts about that network.
- **Appendix E**, "**Practice for Chapter 13: Analyzing Subnet Masks**," lists practice problems associated with Chapter 13. In particular, the practice questions ask you to convert masks between the three formats, and to examine an existing mask, determine the structure of the IP addresses, and calculate the number of hosts/subnet and number of subnets.
- **Appendix F**, "**Practice for Chapter 14: Analyzing Existing Subnets**," lists practice problems associated with Chapter 14. In particular, the practice questions ask you to take an IP address and mask, and find the subnet ID, subnet broadcast address, and range of IP addresses in the subnet.
- **Appendix G**, "**Practice for Chapter 19: Subnet Design**," lists practice problems associated with Chapter 19. In particular, the practice questions ask you to examine a set of requirements, determine which mask (if any) meets those requirements, and choose the best mask based on the requirements. It also asks you to find all the subnet IDs in a classful network when given a single mask used throughout the network.
- **Appendix H**, "**Practice for Chapter 20: Variable-Length Subnet Masks**," lists practice problems associated with Chapter 20, including problems in which you look for a place to add a new VLSM subnet so that no VLSM overlap is created.
- **Appendix I**, "**Practice for Chapter 21: Route Summarization**," lists practice problems associated with Chapter 21. In particular, the practice questions ask you to find the best summary route that includes all the subnets in a list.
- **Appendix J**, "**Practice for Chapter 22: Basic IPv4 Access Control Lists**," lists practice problems associated with

Chapter 22. In particular, the practice questions give you a chance to practice working with ACL wildcard masks.

- **Appendix K**, "**Practice for Chapter 25: Fundamentals of IP Version 6**," lists practice problems associated with Chapter 25. In particular, it provides practice for abbreviating full IPv6 addresses and expanded abbreviated IPv6 addresses.
- **Appendix L**, "**Practice for Chapter 27: Implementing IPv6 on Routers**," lists practice problems associated with Chapter 27. In particular, it provides practice in using the EUI-64 process to build an IPv6 address, and in how to find the solicited node multicast used based on a unicast address.
- **Appendix M**, "**Memory Tables**," holds the key tables and lists from each chapter, with some of the content removed. You can print this appendix and, as a memory exercise, complete the tables and lists. The goal is to help you memorize facts that can be useful on the exams.
- **Appendix N**, "**Memory Tables Answer Key**," contains the answer key for the exercises in Appendix M.
- **Appendix O**, "**Mind Map Solutions**," shows an image of sample answers for all the part-ending mind map exercises.
- **Appendix P**, "**Study Planner**," is a spreadsheet with major study milestones, where you can track your progress through your study.

Reference Information

This short section contains a few topics available for reference elsewhere in the book. You can read these when you first use the book, but you can also skip these topics and refer back to them later. In particular, make sure to note the final page of this Introduction, which lists several contact details, including how to get in touch with Cisco Press.

Install the Pearson IT Certification Practice Test Engine and Questions

The DVD in the book includes the Pearson IT Certification Practice Test (PCPT) engine—software that displays and grades a set of exam-realistic multiple-choice, drag and drop, fill-in-the-blank, and Testlet questions. Using the Pearson IT Certification Practice Test engine, you can either study by going through the questions in Study Mode, or take a simulated ICND1 or CCNA exam that mimics real exam conditions.

The installation process requires two major steps. The DVD in the back of this book has a recent copy of the Pearson IT Certification Practice Test engine. The practice exam—the database of ICND1 and CCNA exam questions—is not on the DVD. After you install the software, the PCPT software will download the latest versions of both the software and the question databases for this book using your Internet connection.

> **Note**
>
> The cardboard DVD case in the back of this book includes both the DVD and a piece of thick paper. The paper lists the activation code for the practice exam associated with this book. *Do not lose the activation code.*

Also on this same piece of paper, on the opposite side from the exam activation code, you will find a one-time-use coupon code that will give you 70 percent off the purchase of the *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide, Premium Edition eBook and Practice Test*.

Install the Software from the DVD

The software installation process is pretty routine as compared with other software installation processes. If you have already installed the Pearson IT Certification Practice Test software from another Pearson product, there is no need for you to reinstall the software. Simply launch the software on your desktop and proceed to activate the practice exam from this book by using the activation code included in the DVD sleeve. The following steps outline the installation process:

Step 1. Insert the DVD into your PC.

Step 2. The software that automatically runs is the Cisco Press software to access and use all DVD-based features, including the exam engine and the DVD-only appendices. From the main menu, click the Install the Exam Engine option.

Step 3. Respond to windows prompts as with any typical software installation process.

The installation process will give you the option to activate your exam with the activation code supplied on the paper in the DVD sleeve. This process requires that you establish a Pearson website login. You will need this login to activate the exam, so please do register when prompted. If you already have a Pearson website login, there is no need to register again. Just use your existing login.

Activate and Download the Practice Exam

When the exam engine is installed, you should then activate the exam associated with this book (if you did not do so during the installation process) as follows:

Step 1. Start the PCPT software from the Windows **Start** menu or from your desktop shortcut icon.

Step 2. To activate and download the exam associated with this book, from the **My Products** or **Tools** tab, click the **Activate** button.

Step 3. At the next screen, enter the activation key from the paper inside the cardboard DVD holder in the back of the book. When it is entered, click the **Activate** button.

Step 4. The activation process will download the practice exam. Click **Next**, and then click **Finish**.

After the activation process is completed, the **My Products** tab should list your new exam. If you do not see the exam, make sure that you have selected the **My Products** tab on the menu. At this point, the software and practice exam are ready to use. Simply select the exam and click the **Open Exam** button.

To update a particular product's exams that you have already activated and downloaded, simply select the Tools tab and click the **Update Products** button. Updating your exams will ensure that you have the latest changes and updates to the exam data.

If you want to check for updates to the PCPT software, simply select the Tools tab and click the **Update Application** button. This will ensure that you are running the latest version of the software engine.

Activating Other Products

The exam software installation process and the registration process only have to happen once. Then for each new product, only a few steps are required. For example, if you buy another new Cisco Press Official Cert Guide or Pearson IT Certification Cert Guide, extract the activation code from the DVD sleeve in the back of that book—you don't even need the DVD at this point. From there, all you have to do is start PCPT (if not still up and running) and perform Steps 2 through 4 from the previous list.

PCPT Exam Databases with This Book

This book includes an activation code that allows you to load a set of practice questions. The questions come in different exams or exam databases. When you install the PCPT software, and type in the activation code, the PCPT software downloads the latest version of all these exam databases. And with the ICND1 book alone, you get six different "exams," or six different sets of questions, as listed in Figure I-2.

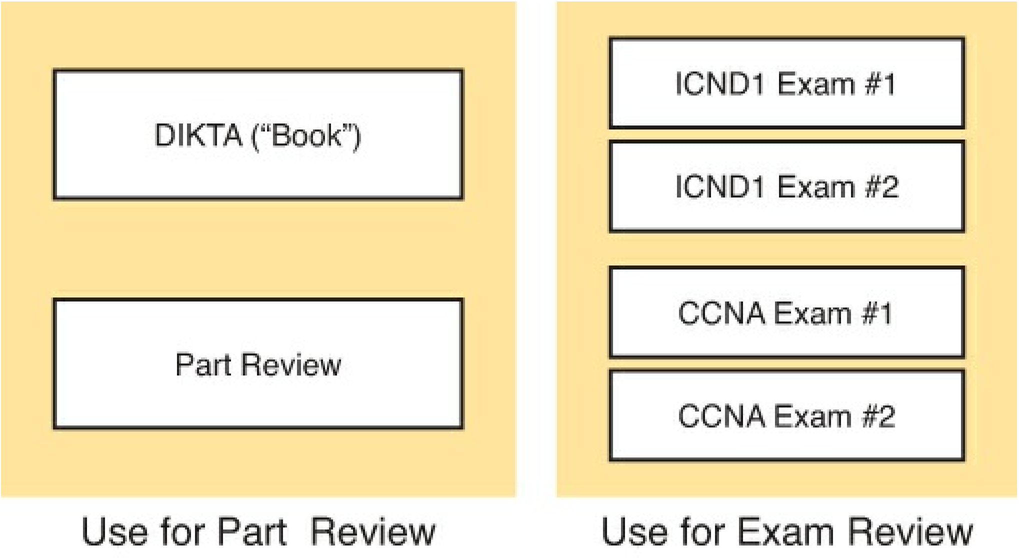


Figure I-2. PCPT Exams/Exam Databases and When to Use Them

You can choose to use any of these exam databases at any time, both in study mode and practice exam mode. However, many people find it best to save some of the exams until exam review time, after you have finished reading the entire book. Figure I-2 begins to suggest a plan, spelled out here:

- During part review, use PCPT to review the DIKTA questions for that part, using study mode.
- During part review, use the questions built specifically for part review (the Part Review questions) for that part of the book, using study mode.
- Save the remaining exams to use with the Final Review chapter, using practice exam mode, as discussed in Chapter 30.

The two modes inside PCPT give you better options for study versus practicing a timed exam event. In study mode, you can see the answers immediately, so you can study the topics more easily. Also, you can choose a subset of the questions in an exam database—for example, you can view questions from only the chapters in one part of the book.

Practice exam mode creates an event somewhat like the actual exam. It gives you a preset number of questions, from all chapters, with a timed event. Practice exam mode also gives you a score for that timed event.

How to View Only DIKTA Questions by Part

Each Part Review section asks you to repeat the Do I Know This Already? (DIKTA) quiz questions from the chapters in that part. While you can simply scan the book pages to review these questions, it is slightly better to review these questions from inside the PCPT software, just to get a little more practice in how to read questions from the testing software. But, you can just read them in the book as well.

To view these DIKTA (book) questions inside the PCPT software, you need to select "Book Questions" and the chapters in this part, using the PCPT menus. To do so, follow these steps:

Step 1. Start the PCPT software.

Step 2. From the main (home) menu, select the item for this product, with a name like **Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide**, and click **Open Exam**.

Step 3. The top of the next window that appears should list some exams; select the check box beside **ICND1 Book Questions** and deselect the other check boxes. This selects the "book" questions, that is, the DIKTA questions from the beginning of each chapter.

Step 4. In this same window, click at the bottom of the screen to deselect all objectives (chapters). Then select the box beside each chapter in the part of the book you are reviewing.

Step 5. Select any other options on the right side of the window.

Step 6. Click **Start** to start reviewing the questions.

How to View Only Part Review Questions by Part

The exam databases you get with this book include a database of questions created solely for study during the Part Review process. DIKTA questions focus more on facts, with basic application. The Part Review questions instead focus more on application, and look more like real exam questions.

To view these questions, follow the same process as you did with DIKTA/Book questions, but select the "Part Review" database instead of the "Book" database. Specifically:

Step 1. Start the PCPT software.

Step 2. From the main (home) menu, select the item for this product, with a name like **CCENT/CCNA ICND1 100-101 Official Cert Guide**, and click **Open Exam**.

Step 3. The top of the next window should list some exams; select the check box beside **Part Review Questions** and deselect the other check boxes. This selects the questions intended for part-ending review.

Step 4. In this same window, click at the bottom of the screen to deselect all objectives, and then select (check) the box beside the book part you want to review. This tells the PCPT software to give you Part Review questions from the selected part.

Step 5. Select any other options on the right side of the window.

Step 6. Click **Start** to start reviewing the questions.

About Mind Maps

Mind maps are a type of visual organization tool that can be used for many purposes. For example, mind maps can be used as an alternative way to take notes.

Mind maps can also be used to improve how your brain organizes concepts. Mind maps stress the connections and relationships between ideas. When you spend time thinking about an area of study, and organize your ideas into a mind map, you strengthen existing mental connections, create new connections, all into your own frame of reference.

In short, mind maps help you internalize what you learn.

Mind Map Mechanics

Each mind map begins with a blank piece of paper or blank window in an application. You then add a large central idea, with branches that move out in any direction. The branches contain smaller concepts, ideas, commands, pictures—whatever idea needs to be represented. Any concepts that can be grouped should be put near each other. As need be, you can create deeper and deeper branches, although for this book's purposes, most mind maps will not go beyond a couple of levels.

Note

While many books have been written about mind maps, Tony Buzan often gets credit for formalizing and popularizing mind maps. You can learn more about mind maps at his website, www.thinkbuzan.com.

For example, Figure I-3 shows a sample mind map that begins to output some of the IPv6 content from Part VII of the book. The central concept of the mind map is IPv6 addressing, and the Part Review activity asks you to think of all facts you learned about IPv6 addressing and organize them with a mind map. The mind map allows a more visual representation of the concepts as compared with just written notes.

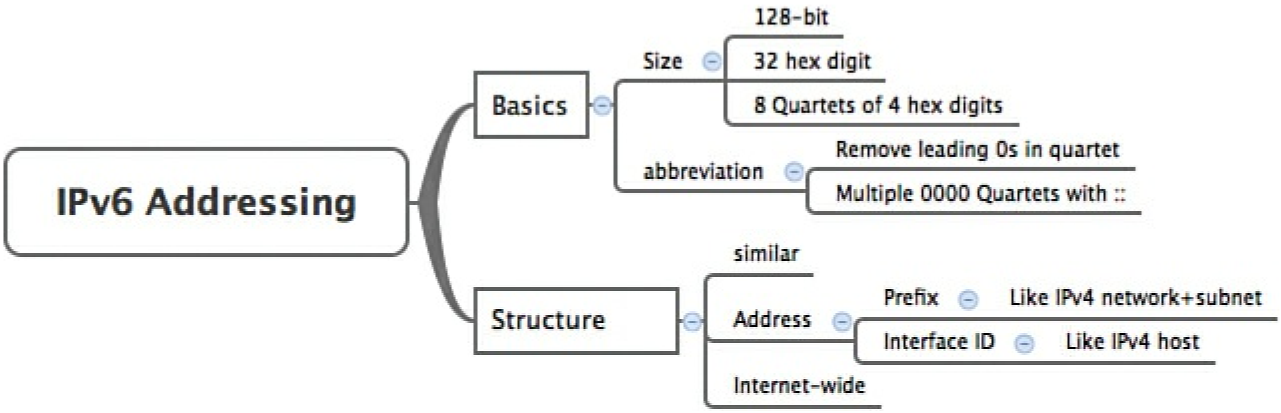


Figure I-3. Sample Mind Map

About Mind Maps Used During Part Review

This book suggests mind-mapping exercises during Part Review. This short topic lists some details about the Part Review mind-mapping exercises, listed in one place for reference.

The Part Review sections use two main types of mind mapping exercises:

Configuration exercises ask you to recall the related configuration commands and group them. For example, in a configuration exercise, related commands that happen to be interface subcommands should be grouped, but as shown as being inside interface configuration mode.

Verification exercises ask you to think about the output of show commands and link the output to either the configuration commands that cause that output or the concepts that explain the meaning of some of that output.

Create these configuration mind maps on paper, using any mind-mapping software, or even any drawing application. Many mind-mapping apps exist as well. Regardless of how you draw them, follow these rules:

- If you have only a little time for this exercise, spend your time making your own mind map, instead of looking at suggested answers. The learning happens when thinking through the problem of making your own mind map.
- Set aside the book and all your notes, and do not look at them when first creating these maps, and do as much as you can without looking at the book or your notes (or Google, or anything else).
- Try all the mind maps listed in a Part Review section before looking at your notes.
- Finally, look at your notes to complete all the mind maps.
- Make a note of where you put your final results so that you can find them later during final exam review.

Finally, when learning to use these tools, take two other important suggestions as well. First, use as few words as possible for each node in your mind map. The point is for you to remember the idea and its connections, rather than explain the concept to someone else. Just write enough to remind yourself of the concept. Second, if the mind map process just is not working for you, discard the tool. Instead, take freeform notes on a blank piece of paper. Try to do the important part of the exercise—the thinking about what concepts go together—without letting the tool get in the way.

About Building Hands-On Skills

You need skills in using Cisco routers and switches, specifically the Cisco command-line interface (CLI). The Cisco CLI is a text-based command-and-response user interface in which you type a command and the device (a router or switch) displays messages in response. To answer Sim and Simlet questions on the exams, you need to know a lot of commands, and you need to be able to navigate to the right place in the CLI to use those commands.

The best way to master these commands is to use them. Sometime during your initial reading of the first part of this book, you need to decide how you personally plan to build your CLI skills. This next topic discusses your options for getting the tools you need to build CLI skills.

Overview of Lab Options

To effectively build your hands-on CLI skills, you either need real routers and switches, or at least something that acts like routers and switches. People who are new to Cisco technology often choose from a few options to get those skills.

First, you can use real Cisco routers and switches. You can buy them, new or used, or borrow them at work. You can rent them for a fee. You can even rent virtual Cisco router and switch lab pods from Cisco, in an offering called Cisco Learning Labs.

Simulators provide another option. Router and switch Simulators are software products that mimic the behavior of the Cisco CLI, generally for the purpose of allowing people to learn. These products have an added advantage when learning: They usually have lab exercises as well.

Simulators come in many shapes and sizes, but the publisher sells Simulators that are designed to help you with CCENT and CCNA study—plus they match this book! The Pearson CCENT Network Simulator and the Pearson CCNA Network Simulator both provide an excellent environment to practice the commands, as well as hundreds of focused labs to help you learn what you need to know for the exams. Both products have the same software code base. The CCNA product simply has labs for both

ICND1 and ICND2, while the CCENT product has only the ICND1 labs.

This book does not tell you what option you have to use, but you should plan on getting some hands-on practice somehow. The important thing to know is that most people need to practice using the Cisco CLI to be ready to pass these exams.

I (Wendell) have collected some information and opinions about this decision on my website, at certskills.com/labgear. Those pages link to sites for Dynamips and for the Pearson Simulator. Also, because the information never seemed to exist in any one place, this website includes many details about how to build a CCNA lab using used real Cisco routers and switches.

A Quick Start with Pearson Network Simulator Lite

The decision of how to get hands-on skills can be a little scary at first. The good news: You have a free and simple first step: Install the Pearson NetSim Lite that comes with this book.

This lite version of the best-selling CCNA Network Simulator from Pearson provides you with a means, right now, to experience the Cisco command-line interface (CLI). There's no need to go buy real gear or buy a full simulator to start learning the CLI. Just install it from the DVD in the back of this book.

Of course, one reason that NetSim Lite comes on the DVD is that the publisher hopes you will buy the full product. However, even if you do not use the full product, you can still learn from the labs that come with NetSim Lite while deciding about what options to pursue.

> **Note**
>
> The ICND1 and ICND2 books each contain a different version of the Sim Lite product, each with labs related to the matching book. If you bought both books, make sure that you install both Sim Lite products.

For More Information

If you have any comments about the book, submit them through www.ciscopress.com. Just go to the website, select Contact Us, and type your message.

Cisco might make changes that affect the CCNA Routing and Switching certification from time to time. You should always check www.cisco.com/go/ccna and www.cisco.com/go/ccent for the latest details.

The *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide* helps you attain both CCENT and CCNA Routing and Switching certifications. This is the CCENT/CCNA ICND1 certification book from the only Cisco-authorized publisher. We at Cisco Press believe that this book certainly can help you achieve CCNA Routing and Switching certification, but the real work is up to you! I trust that your time will be well spent.

Getting Started

You just got this book. You have probably already read (or quickly skimmed) the Introduction. And you are wondering, is this where I really start reading, or can I skip ahead to Chapter 1?

Stop to read this "Getting Started" section to think about how you will study for this exam. Your study will go much better if you take time (maybe 15 minutes) to think about a few key points about how to study, before starting on this journey that will take you many hours, over many weeks. That's what this "Getting Started" section will help you do.

A Brief Perspective on Cisco Certification Exams

Cisco sets the bar pretty high for passing the ICND1, ICND2, and/or CCNA exams. Most anyone can study and pass these exams, but it takes more than just a quick read through the book and the cash to pay for the exam.

The challenge of these exams comes from many angles. Each of these exams covers a lot of concepts, as well as many commands specific to Cisco devices. Beyond knowledge, these Cisco exams also require deep skills. You must be able to analyze and predict what really happens in a network. You must be able to configure Cisco devices to work correctly in those networks. And you must be ready to troubleshoot problems when the network does not work correctly.

The more challenging questions on these exams work a lot like a jigsaw puzzle—but with four out of every five puzzle pieces not even in the room. To solve the puzzle, you have to mentally re-create the missing pieces. To do that, you must know each networking concept and remember how the concepts work together. You also have to match the concepts with what happens on the devices with the configuration commands that tell the devices what to do. You also have to connect the concepts, and the configuration, with the meaning of the output of various troubleshooting commands, to analyze how the network is working and why it is not working right now.

For example, you need to know IP subnetting well, and that topic includes some math. A simple question—one that might be too simple to be a real exam question—would tell you enough of the numbers so that all you have to do is the equivalent of a little addition or multiplication to find a number called a subnet ID.

A more exam-realistic question makes you connect concepts together to set up the math problem. For example, a question might give you a network diagram and ask you to list the subnet ID used in one part of the diagram. But the diagram has no numbers at all. Instead, you have the output of a command from a router, for example, the **show ip ospf database** command, which does list some numbers. But before you can use those numbers, you might need to predict how the devices are configured and what other troubleshooting commands would tell you. So you end up with a question like a puzzle, as shown in Figure 1. The question puts some pieces in the right place; you have to find other pieces using different commands and by applying your knowledge. And some pieces will just remain unknown for a given question.

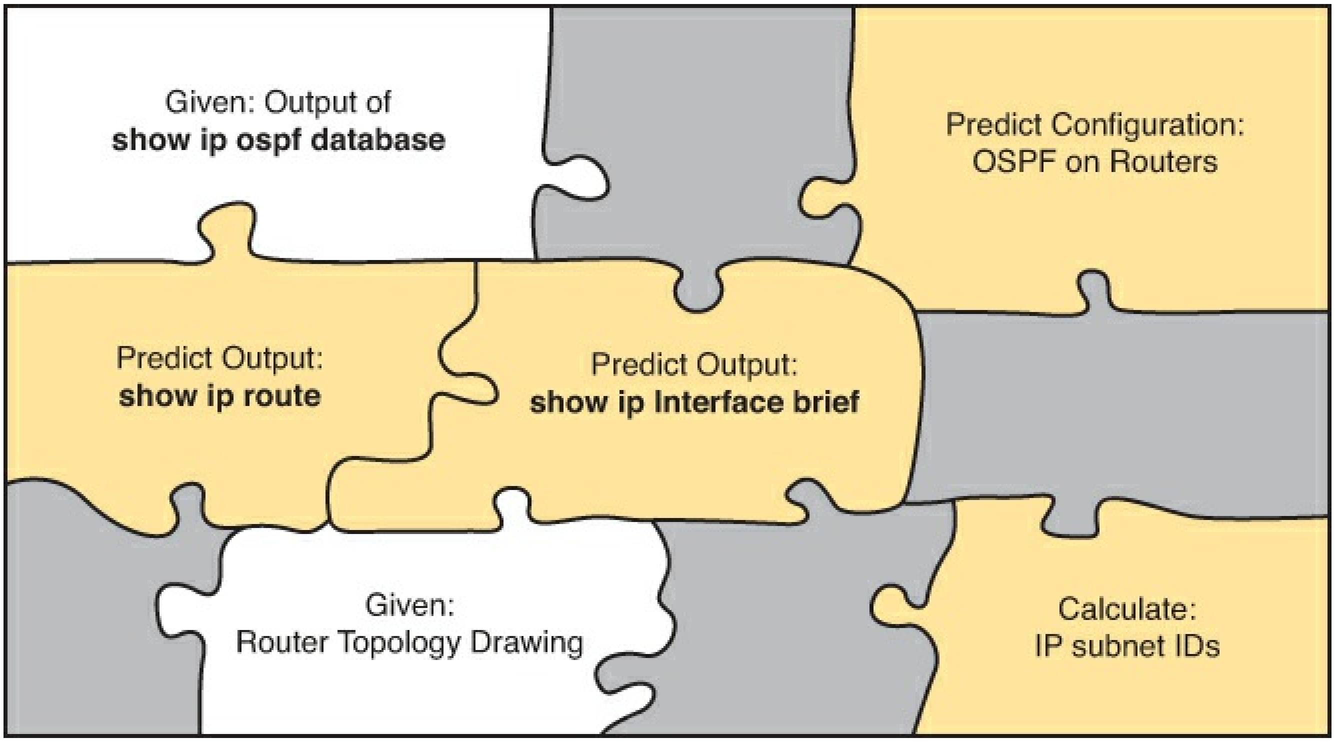


Figure 1. Filling in Puzzle Pieces with Your Analysis Skills

These skills require that you prepare by doing more than just reading and memorizing what you read. Of course, you will need to read many pages in this book to learn many individual facts and how these facts are related to each other. But a big part of this book lists exercises beyond reading, exercises that help you build the skills to solve these networking puzzles.

Suggestions for How to Approach Your Study with This Book

While these exams are challenging, many people pass them every day. So, what do you need to do to be ready to pass, beyond reading and remembering all the facts? You need to develop skills. You need to mentally link each idea with other related ideas. Doing that requires additional work. To help you along the way, the next few pages give you five key perspectives about how to use this book to build those skills and make those connections, before you dive into this exciting but challenging world of learning networking on Cisco gear.

Not One Book: 29 Short Read-and-Review Sessions

First, look at your study as a series of read-and-review tasks, each on a relatively small set of related topics.

Each of the core chapters of this book (1 through 29) have around 22 pages of content on average. If you glance around any of those chapters, you will find a heading called "Foundation Topics" on about the fifth page of each chapter. From there to the "Exam Preparation Tasks" section at the end of the chapter, the chapters average about 22 pages.

So, do not approach this book as one big book. Treat the task of your first read of a chapter as a separate task. Anyone can read 22 pages. Having a tough day? Each chapter has two or three major sections, so read just one of them. Or, do some related labs or review something you have already read. This book organizes the content into topics of a more manageable size to give you something more digestible to manage your study time throughout the book.

For Each Chapter, Do Not Neglect Practice

Next, plan to use the practice tasks at the end of each chapter.

Each chapter ends with practice and study tasks under a heading "Exam Preparation Tasks." Doing these tasks, and doing them at the end of the chapter, really does help you get ready. Do not put off using these tasks until later! The chapter-ending "Exam Preparation Tasks" section helps you with the first phase of deepening your knowledge and skills of the key topics, remembering terms and linking the concepts together in your brain so that you can remember how it all fits together.

The following list describes the majority of the activities you will find in "Exam Preparation Tasks" sections:

- Review key topics
- Complete memory tables
- Define key terms
- Review command summary tables
- Review feature configuration checklists
- Do subnetting exercises

Approach each chapter with the same plan. You can choose to read the entire core (Foundation Topics) section of each chapter, or you can choose to skim some chapters, based on your score on the "Do I Know This Already?" (DIKTA) quiz, a pre-chapter self-assessment quiz at the beginning of most chapters. However, regardless of whether you skim or read thoroughly, do the study tasks in the "Exam Preparation Tasks" section at the end of the chapter. Figure 2 shows the overall flow.

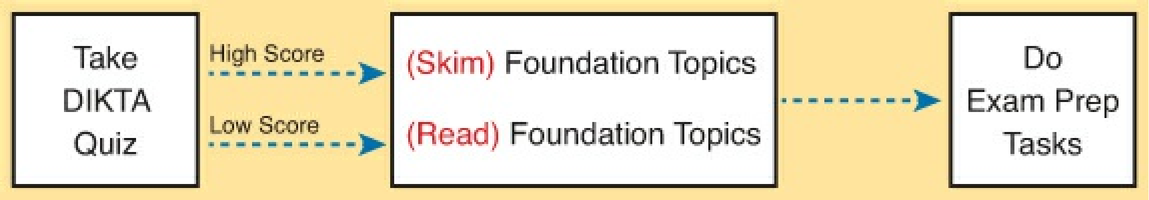
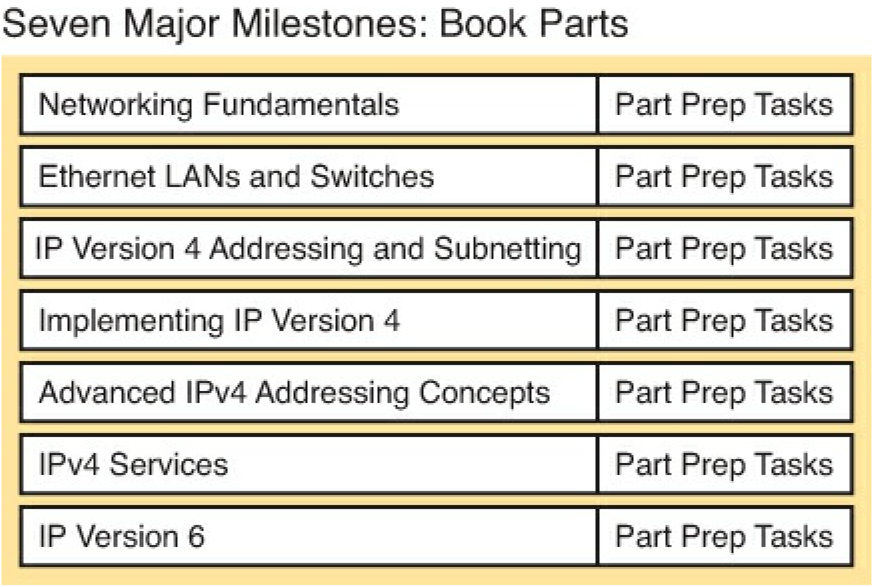


Figure 2. Suggested Approach to Each Chapter

Use Book Parts for Major Milestones

Third, view the book as having seven major milestones, one for each major topic.

Beyond the more obvious organization into chapters, this book also organizes the chapters into seven major topic areas called book parts. Completing each part means that you have completed a major area of study. At the end of each part, take a little extra time. Do the Part Review tasks at the end of each part. Ask yourself where you are weak and where you are strong. And give yourself some reward for making it to a major milestone. Figure 3 lists the seven parts in this book.



Networking Fundamentals	Part Prep Tasks
Ethernet LANs and Switches	Part Prep Tasks
IP Version 4 Addressing and Subnetting	Part Prep Tasks
Implementing IP Version 4	Part Prep Tasks
Advanced IPv4 Addressing Concepts	Part Prep Tasks
IPv4 Services	Part Prep Tasks
IP Version 6	Part Prep Tasks

Figure 3. Parts as Major Milestones

The tasks in the Part Review sections focus on helping you apply concepts (from that book part) to new scenarios for the exam. Some tasks use sample test questions so that you can think through and analyze a problem. This process helps you refine what you know and to realize what you did not quite yet understand. Some tasks use mind map exercises that help you mentally connect the theoretical concepts with the configuration and verification commands. These Part Review activities help build these skills.

Note that the part review directs you to use the Pearson Certification Practice Test (PCPT) software to access the practice questions. Each part review tells you to repeat the DIKTA questions, but using the PCPT software. Each part review also directs you how to access a specific set of questions reserved for reviewing concepts at part review. Note that the PCPT software and exam databases with this book give you the rights to additional questions as well; Chapter 30, "Final Review," gives some recommendations on how to best use those questions for your final exam preparation.

Also, consider setting a goal date for finishing each part of the book, and a reward as well! Plan a break, some family time, some time out exercising, eating some good food—whatever helps you get refreshed and motivated for the next part.

Use the Final Review Chapter to Refine Skills

Fourth, do the tasks outlined in the final preparation chapter (Chapter 30) at the end of this book.

The Final Review chapter has two major goals. First, it helps you further develop the analysis skills you need to answer the more complicated questions on the exam. Many questions require that you connect ideas about concepts, configuration, verification, and troubleshooting. More reading on your part does not develop all these skills; this chapter's tasks give you activities to further develop these skills.

The tasks in the Final Review chapter also help you find your weak areas. This final element gives you repetition with high-challenge exam questions, uncovering any gaps in your knowledge. Many of the questions are purposefully designed to test your knowledge of the most common mistakes and misconceptions, helping you avoid some of the common pitfalls people experience with the actual exam.

Set Goals and Track Your Progress

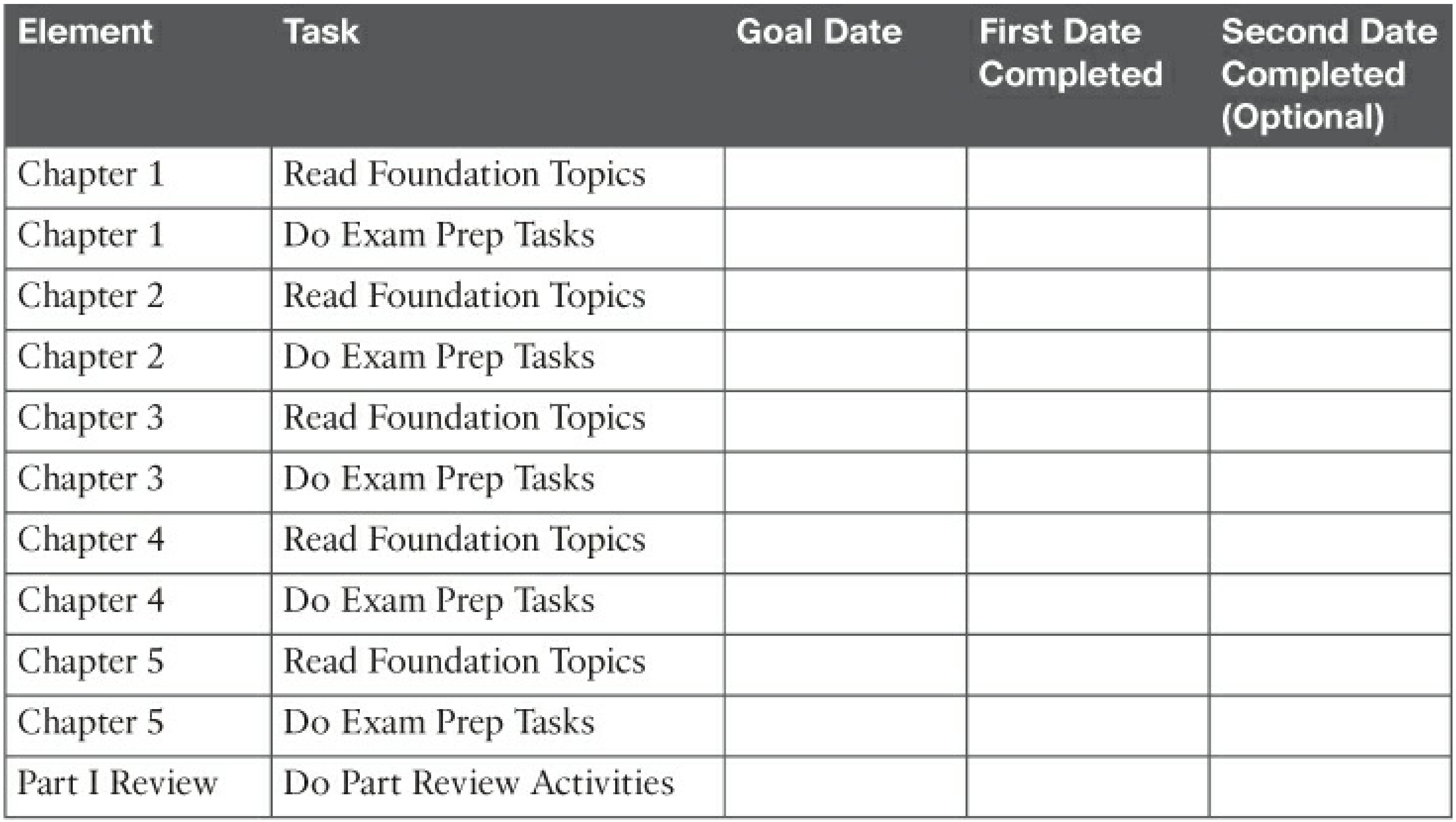
Finally, before you start reading the book and doing the rest of these study tasks, take the time to make a plan, set some goals, and be ready to track your progress.

While making lists of tasks might or might not appeal to you, depending on your personality, goal setting can help everyone studying for these exams. And to do the goal setting, you need to know what tasks you plan to do.

As for the list of tasks to do when studying, you do not have to use a detailed task list. (You could list every single task in every chapter-ending "Exam Preparation Tasks" section, every task in the Part Review tasks section, and every task in the Final Preparation Tasks chapter.) However, listing the major tasks can be enough.

You should track at least two tasks for each typical chapter: reading the "Foundation Topics" section and doing the "Exam Preparation Tasks" section at the end of the chapter. And of course, do not forget to list tasks for Part Reviews and Final Review. Table 1 shows a sample for Part I of this book.

Table 1. Sample Excerpt from a Planning Table



Element	Task	Goal Date	First Date Completed	Second Date Completed (Optional)
Chapter 1	Read Foundation Topics			
Chapter 1	Do Exam Prep Tasks			
Chapter 2	Read Foundation Topics			
Chapter 2	Do Exam Prep Tasks			
Chapter 3	Read Foundation Topics			
Chapter 3	Do Exam Prep Tasks			
Chapter 4	Read Foundation Topics			
Chapter 4	Do Exam Prep Tasks			
Chapter 5	Read Foundation Topics			
Chapter 5	Do Exam Prep Tasks			
Part I Review	Do Part Review Activities			

Note

Appendix P, "Study Planner," on the DVD that comes with this book, contains a complete planning checklist like Table 1 for the tasks in this book. This spreadsheet allows you to update and save the file to note your goal dates and the tasks you have completed.

Use your goal dates as a way to manage your study, and not as a way to get discouraged if you miss a date. Pick reasonable dates that you can meet. When setting your goals, think about how fast you read and the length of each chapter's "Foundation Topics" section, as listed in the Table of Contents. Then, when you finish a task sooner than planned, move up the next few goal dates.

If you miss a few dates, do not start skipping the tasks listed at the ends of the chapters! Instead, think about what is impacting your schedule—real life, commitments, and so on—and either adjust your goals or work a little harder on your study.

Two Options When Studying for the 200-120 CCNA Exam

To get a CCNA certification, you choose either a one-exam or two-exam path.

When using the two-exam path, use each book separately, and take the matching Cisco exam. In other words, use the *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*, then pass the 100-101 ICND1 exam, and then do the same with the *Cisco CCNA Routing and Switching ICND2 200-101 Official Cert Guide* and the 200-101 ICND2 exam.

The one-exam path gives you a couple of study options. The 200-120 CCNA exam covers the topics in the combined ICND1 and ICND2 books. The only question is when to read each part of the two books. Two reasonable options exist when going with the one-exam option:

- Complete all the ICND1 book, and then move on to the ICND2 book.
- Move back and forth between the ICND1 and ICND2 books, by part, based on topics.

While the first option is pretty obvious, the second one is less obvious. So, Figure 4 shows a study plan when using the one-exam option, and you want to move back and forth between the two books. Why move back and forth? To read about similar topics all at once, as shown in Figure 4.

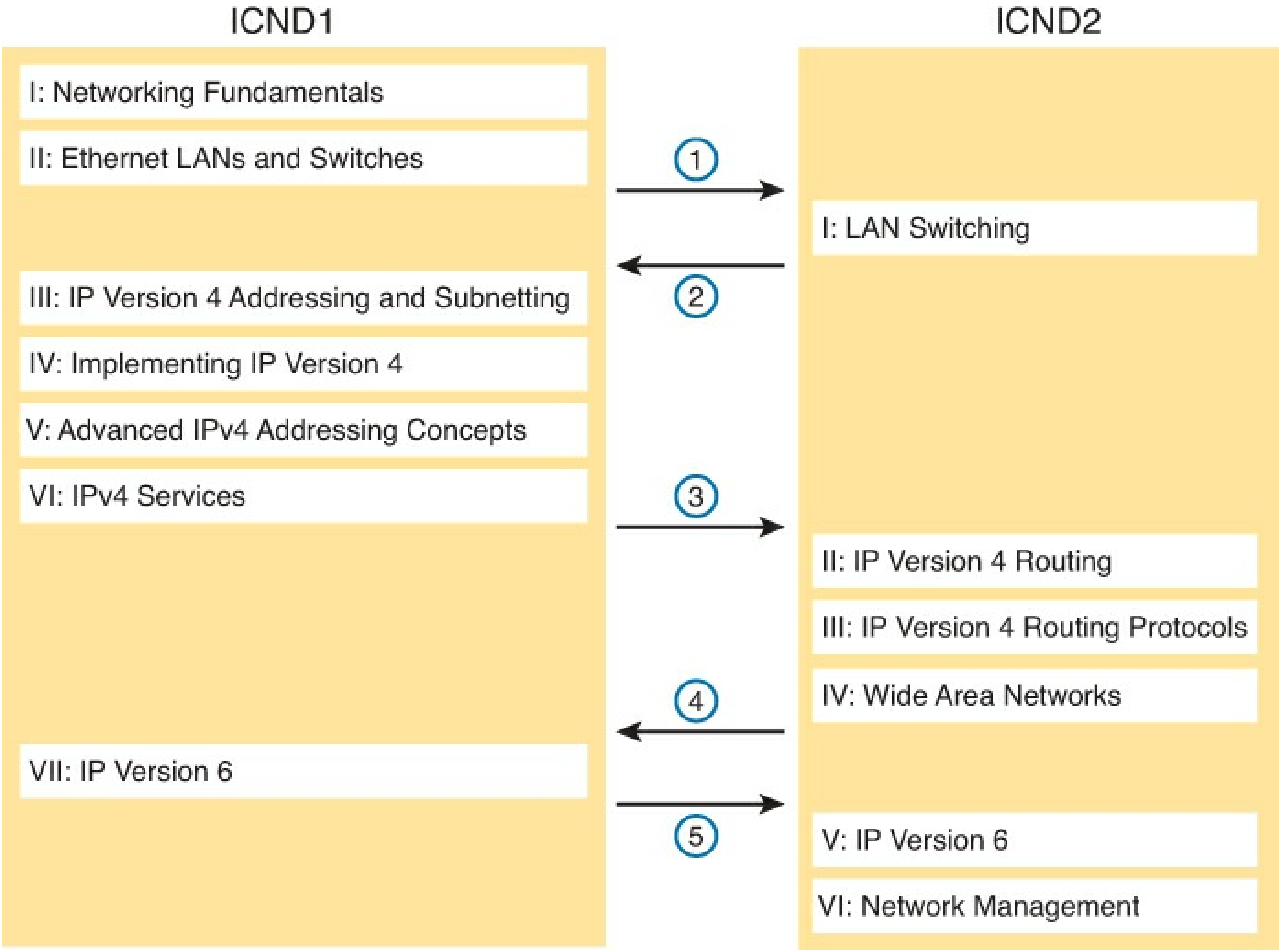

ICND1
I: Networking Fundamentals
II: Ethernet LANs and Switches
III: IP Version 4 Addressing and Subnetting
IV: Implementing IP Version 4
V: Advanced IPv4 Addressing Concepts
VI: IPv4 Services
VII: IP Version 6
ICND2
I: LAN Switching
II: IP Version 4 Routing
III: IP Version 4 Routing Protocols
IV: Wide Area Networks
V: IP Version 6
VI: Network Management
①
②
③
④
⑤

Figure 4. Alternate Reading Plan for CCNA—Moving Between Books by Part

Note that you should wait to use the Final Review chapter of either book until you complete both books. However, do the Part Review activities at the end of each part.

Other Small Tasks Before Getting Started

You will need to do a few overhead tasks to install software, find some PDFs, and so on. You can do these tasks now, or do them in your spare moments when you need a study break during the first few chapters of the book. But do these early, so that if you do stumble upon an installation problem, you have time to work through it before you need a particular tool.

Register (for free) at the Cisco Learning Network (CLN, http://learningnetwork.cisco.com) and join the CCENT and CCNA study groups. These mailing lists allow you to lurk and participate in discussions about topics related to CCENT (ICND1) and CCNA (ICND1 + ICND2). Register, join the groups, and set up an email filter to redirect the messages to a separate folder. Even if you do not spend time reading all the posts yet, later, when you have time to read, you can browse through the posts to find interesting topics. Or just search the posts from the CLN website.

Find and print a copy of Appendix M, "Memory Tables." Many of the Chapter Review sections use this tool, in which you take the incomplete tables from the appendix and complete the table to help you remember some key facts.

If you bought an eBook version of this book, find and download the media files (videos and Sim Lite software) per the instructions supplied on the last page of the eBook file under the heading "Where Are the Companion Files?"

Install the PCPT exam software and activate the exams. For more details on how to load the software, refer to the Introduction, under the heading "Install the Pearson Certification Practice Test Engine and Questions."

Finally, install the Sim Lite software (unless you bought the full simulator product already). The Sim Lite that comes with this book contains a subset of the lab exercises in the full Pearson Network Simulator product.

Getting Started—Now

Now dive in to your first of many short, manageable tasks: reading Chapter 1, "The TCP/IP and OSI Networking Models." Enjoy!

Part I: Networking Fundamentals

This first part of the book introduces the most important topics in TCP/IP networking. Chapter 1 introduces the terms, concepts, and protocols for TCP/IP. Chapters 2 and 3 look at how networking devices send data to each other over a physical link, with Chapter 2 focusing on links between nearby devices (local-area networks) and Chapter 3 focusing on links between far-away devices (wide-area networks).

Chapter 4 focuses on the rules of IP routing, which pulls the LAN and WAN links together by forwarding data all the way from one user device to another. Finally, Chapter 5 looks at several other topics, mostly related to how applications make use of the TCP/IP network.

Chapter 1: The TCP/IP and OSI Networking Models

Chapter 2: Fundamentals of Ethernet LANs

Chapter 3: Fundamentals of WANs

Chapter 4: Fundamentals of IPv4 Addressing and Routing

Chapter 5: Fundamentals of TCP/IP Transport and Applications

Part I Review

Chapter 1. The TCP/IP and OSI Networking Models

This chapter covers the following exam topics:

Operation of IP Data Networks

Recognize the purpose and functions of various network devices such as Routers, Switches, Bridges and Hubs.

Select the components required to meet a given network specification.

Describe the purpose and basic operation of the protocols in the OSI and TCP/IP models.

Welcome to the first chapter in your study for CCENT and CCNA! This chapter begins Part I, which focuses on the basics of networking. Because networks require all the devices to follow the rules, this part starts with a discussion of networking models, which gives you a big-picture view of the networking rules.

You can think of a networking model as you think of a set of architectural plans for building a house. A lot of different people work on building your house, such as framers, electricians, bricklayers, painters, and so on. The blueprint helps ensure that all the different pieces of the house work together as a whole. Similarly, the people who make networking products, and the people who use those products to build their own computer networks, follow a particular networking model. That networking model defines rules about how each part of the network should work, as well as how the parts should work together, so that the entire network functions correctly.

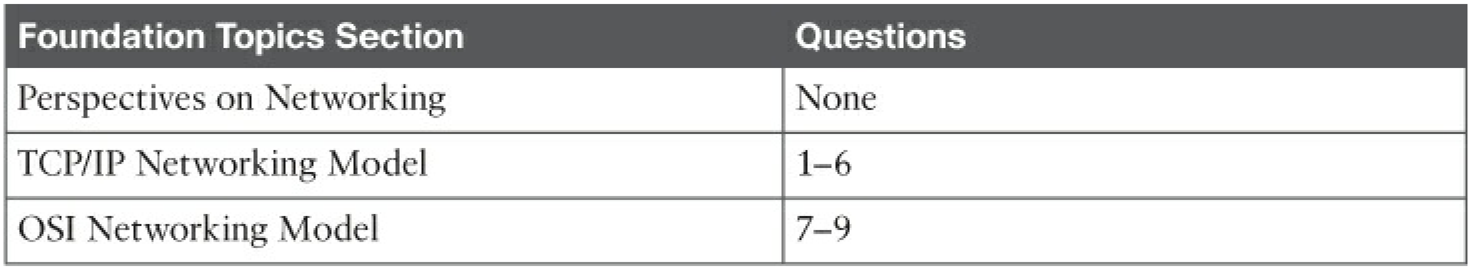
The CCNA exams include detailed coverage of one networking model: Transmission Control Protocol/Internet Protocol (TCP/IP). TCP/IP is the most pervasively used networking model in the history of networking. You can find support for TCP/IP on practically every computer operating system (OS) in existence today, from mobile phones to mainframe computers. Every network built using Cisco products today supports TCP/IP. And not surprisingly, the CCNA exams focus heavily on TCP/IP.

The ICND1 exam, and the ICND2 exam to a small extent, also covers a second networking model, called the Open Systems Interconnection (OSI) reference model. Historically, OSI was the first large effort to create a vendor-neutral networking model. Because of that timing, many of the terms used in networking today come from the OSI model, so this chapter's section on OSI discusses OSI and the related terminology.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 1-1. Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Perspectives on Networking	None
TCP/IP Networking Model	1–6
OSI Networking Model	7–9

1. Which of the following protocols are examples of TCP/IP transport layer protocols? (Choose two answers.)

   a. Ethernet
   b. HTTP
   c. IP
   d. UDP
   e. SMTP
   f. TCP

2. Which of the following protocols are examples of TCP/IP data link layer protocols? (Choose two answers.)

   a. Ethernet
   b. HTTP
   c. IP
   d. UDP
   e. SMTP
   f. TCP
   g. PPP

3. The process of HTTP asking TCP to send some data and making sure that it is received correctly is an example of what?

   a. Same-layer interaction
   b. Adjacent-layer interaction

c. OSI model
d. All of these answers are correct.

4. The process of TCP on one computer marking a TCP segment as segment 1, and the receiving computer then acknowledging the receipt of TCP segment 1 is an example of what?
   a. Data encapsulation
   b. Same-layer interaction
   c. Adjacent-layer interaction
   d. OSI model
   e. All of these answers are correct.
5. The process of a web server adding a TCP header to the contents of a web page, followed by adding an IP header and then adding a data link header and trailer is an example of what?
   a. Data encapsulation
   b. Same-layer interaction
   c. OSI model
   d. All of these answers are correct.
6. Which of the following terms is used specifically to identify the entity created when encapsulating data inside data link layer headers and trailers?
   a. Data
   b. Chunk
   c. Segment
   d. Frame
   e. Packet
7. Which OSI layer defines the functions of logical network-wide addressing and routing?
   a. Layer 1
   b. Layer 2
   c. Layer 3
   d. Layer 4
   e. Layer 5, 6, or 7
8. Which OSI layer defines the standards for cabling and connectors?
   a. Layer 1
   b. Layer 2
   c. Layer 3
   d. Layer 4
   e. Layer 5, 6, or 7
9. Which of the following terms are not valid terms for the names of the seven OSI layers? (Choose two answers.)
   a. Application
   b. Data link
   c. Transmission
   d. Presentation
   e. Internet
   f. Session

Answers to the "Do I Know This Already?" quiz:

1 D and F **2** A and G **3** B **4** B **5** A **6** D **7** C **8** A **9** C and E

Foundation Topics

This chapter introduces some of the most basic ideas about computer networking, while also defining the structure of two networking models: TCP/IP and OSI. The chapter begins with a brief introduction of how most people view a network, which hopefully connects with where you are to start your CCNA journey. The middle of this chapter introduces networking by explaining some of the key features of TCP/IP. The chapter closes with some additional concepts and terminology related to the OSI model.

Perspectives on Networking

So, you are new to networking. Like many people, your perspective about networks might be that of a user of the network, as opposed to the network engineer who builds networks. For some, your view of networking might be based on how you use the Internet, from home, using a high-speed Internet connection like DSL or cable TV, as shown in Figure 1-1.

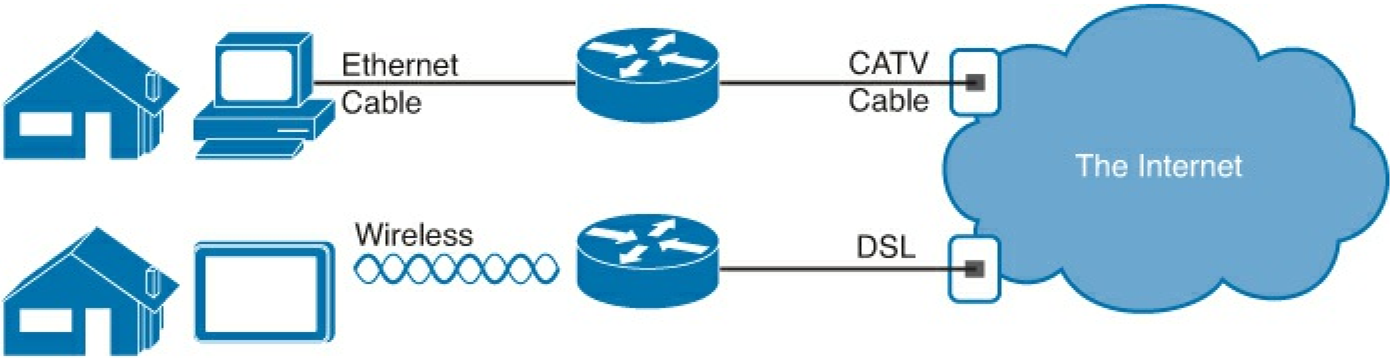


Figure 1-1. End-User Perspective on High-Speed Internet Connections

The top part of the figure shows a typical high-speed cable Internet user. The PC connects to a cable modem using an Ethernet cable. The cable modem then connects to a cable TV (CATV) outlet in the wall using a round coaxial cable—the same kind of cable used to connect your TV to the CATV wall outlet. Because cable Internet services provide service continuously, the user can just sit down at the PC and start sending e-mail, browsing websites, making Internet phone calls, and using other tools and applications as well.

The lower part of the figure uses two different technologies. First, the tablet computer uses wireless technology that goes by the name wireless local-area network (wireless LAN), or Wi-Fi, instead of using an Ethernet cable. In this example, the router uses a different technology, digital subscriber line (DSL), to communicate with the Internet.

The CCNA exams, and particularly the ICND1 (100-101) exam, include the technologies used to create networks at a home (as shown in Figure 1-1), but with even more focus on networking technology used inside a company. The Information Technology (IT) world refers to a network created by one corporation, or enterprise, for the purpose of allowing its employees to communicate, as an *enterprise network*. The smaller networks at home, when used for business purposes, often go by the name small office home office (SOHO) networks.

Users of enterprise networks have some idea about the enterprise network at their company or school. People realize that they use a network for many tasks. PC users might realize that their PC connects through an Ethernet cable to a matching wall outlet, as shown at the top of Figure 1-2. Those same users might use wireless LANs with their laptop when going to a meeting in the conference room as well. Figure 1-2 shows these two end-user perspectives on an enterprise network.

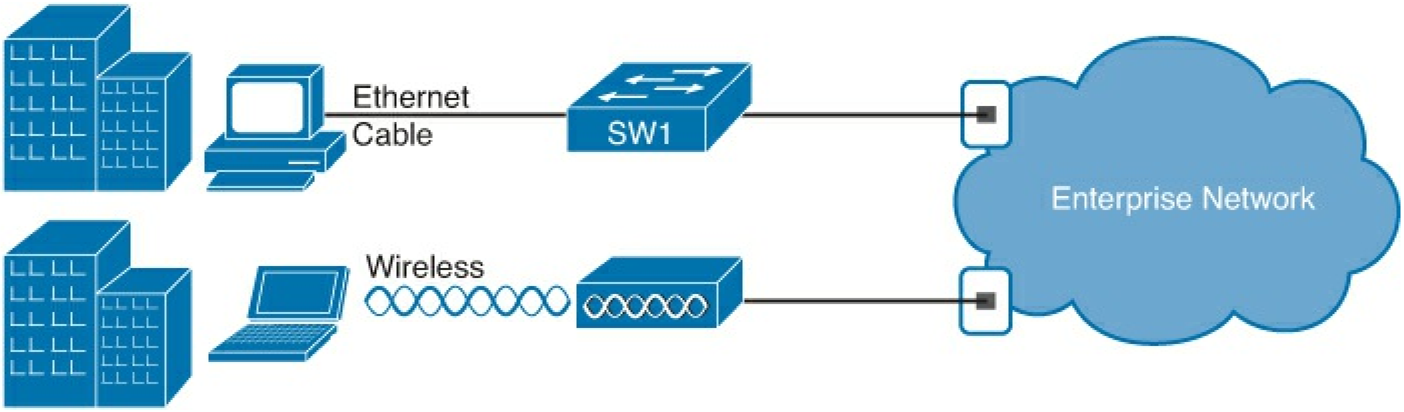


Figure 1-2. Example Representation of an Enterprise Network

Note

In networking diagrams, a cloud represents a part of a network whose details are not important to the purpose of the diagram. In this case, Figure 1-2 ignores the details of how to create an Enterprise network.

Some users might not even have a concept of the network at all. Instead, these users just enjoy the functions of the network—the ability to post messages to social media sites, make phone calls, search for information on the Internet, listen to music, and download countless apps to their phones—without caring about how it works or how their favorite device connects to the network.

Regardless of how much you already know about how networks work, this book, and the related certifications, help you learn how networks do their job. That job is simply this: moving data from one device to another. The rest of this chapter, and the rest of this first part of the book, reveals the basics of how to build both SOHO and enterprise networks so that they can deliver data between two devices.

In the building business, much work happens before you nail the first boards together. The process starts with some planning, an understanding of how to build a house, and some architectural blueprints of how to build that specific house. Similarly, the journey toward building any computer network does not begin by installing devices and cables, but instead by looking at the architectural plans for those modern networks: the TCP/IP model.

TCP/IP Networking Model

A *networking model*, sometimes also called either a *networking architecture* or *networking blueprint*, refers to a comprehensive set of documents. Individually, each document describes one small function required for a network; collectively, these documents define everything that should happen for a computer network to work. Some documents define a *protocol*, which is a set of logical rules that devices must follow to communicate. Other documents define some physical requirements for networking. For example, a document could define the voltage and current levels used on a particular cable when transmitting data.

You can think of a networking model as you think of an architectural blueprint for building a house. Sure, you can build a house without the blueprint. However, the blueprint can ensure that the house has the right foundation and structure so that it will not fall down, and it has the correct hidden spaces to accommodate the plumbing, electrical, gas, and so on. Also, the many different people that build the house using the blueprint—such as framers, electricians, bricklayers, painters, and so on—know that if they follow the blueprint, their part of the work should not cause problems for the other workers.

Similarly, you could build your own network—write your own software, build your own networking cards, and so on—to create a network. However, it is much easier to simply buy and use products that already conform to some well-known networking model or blueprint. Because the networking product vendors build their products with some networking model in mind, their products should work well together.

History Leading to TCP/IP

Today, the world of computer networking uses one networking model: TCP/IP (Transmission Control Protocol/Internet Protocol). However, the world has not always been so simple. Once upon a time, networking protocols didn't exist, including TCP/IP. Vendors created the first networking protocols; these protocols supported only that vendor's computers. For example, IBM published its Systems Network Architecture (SNA) networking model in 1974. Other vendors also created their own proprietary networking models. As a result, if your company bought computers from three vendors, network engineers often had to create three different networks based on the networking models created by each company, and then somehow connect those networks, making the combined networks much more complex. The left side of Figure 1-3 shows the general idea of what a company's enterprise network might have looked back in the 1980s, before TCP/IP became common in enterprise internetworks.

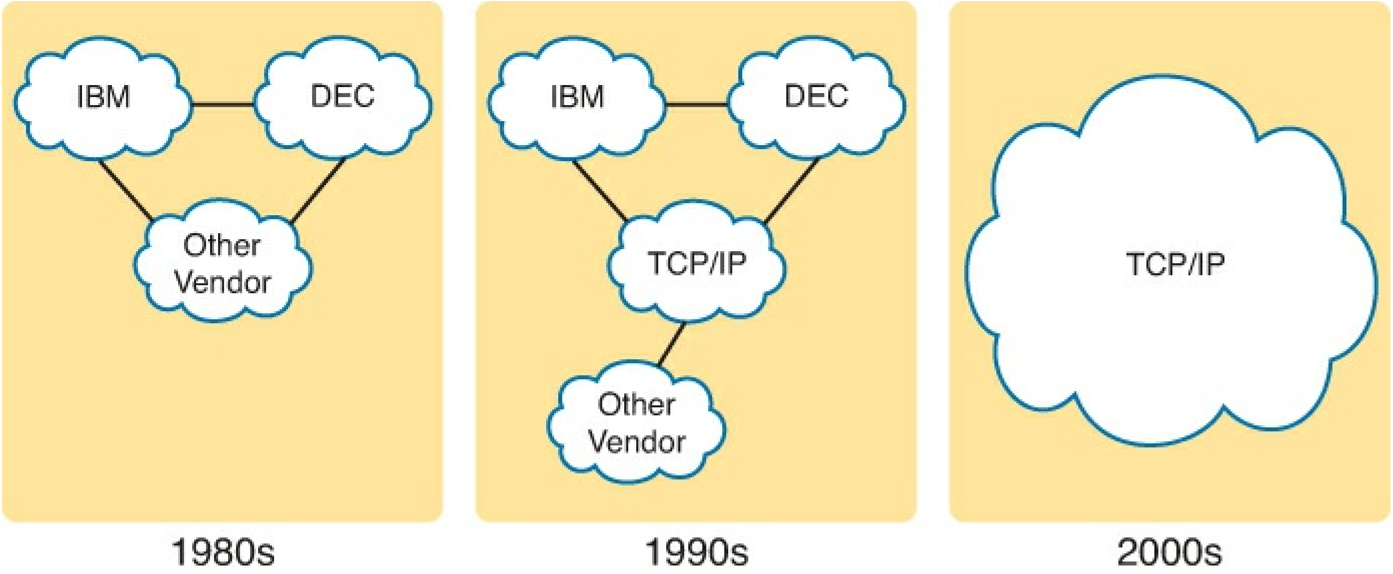


Figure 1-3. Historical Progression: Proprietary Models to the Open TCP/IP Model

Although vendor-defined proprietary networking models often worked well, having an open, vendor-neutral networking model would aid competition and reduce complexity. The International Organization for Standardization (ISO) took on the task to create such a model, starting as early as the late 1970s, beginning work on what would become known as the Open Systems Interconnection (OSI) networking model. ISO had a noble goal for the OSI model: to standardize data networking protocols to allow communication between all computers across the entire planet. ISO worked toward this ambitious and noble goal, with participants from most of the technologically developed nations on Earth participating in the process.

A second, less formal effort to create an open, vendor-neutral, public networking model sprouted forth from a U.S. Department of Defense (DoD) contract. Researchers at various universities volunteered to help further develop the protocols surrounding the original DoD work. These efforts resulted in a competing open networking model called TCP/IP.

During the 1990s, companies began adding OSI, TCP/IP, or both to their enterprise networks. However, by the end of the 1990s, TCP/IP had become the common choice, and OSI fell away. The center part of Figure 1-3 shows the general idea behind enterprise networks in that decade—still with networks built upon multiple networking models, but including TCP/IP.

Here in the twenty-first century, TCP/IP dominates. Proprietary networking models still exist, but they have mostly been discarded in favor of TCP/IP. The OSI model, whose development suffered in part because of a slower formal standardization process as compared with TCP/IP, never succeeded in the marketplace. And TCP/IP, the networking model originally created almost entirely by a bunch of volunteers, has become the most prolific network model ever, as shown on the right side of Figure 1-3.

In this chapter, you will read about some of the basics of TCP/IP. Although you will learn some interesting facts about TCP/IP, the true goal of this chapter is to help you understand what a networking model or networking architecture really is and how it works.

Also in this chapter, you will learn about some of the jargon used with OSI. Will any of you ever work on a computer that is using the full OSI protocols instead of TCP/IP? Probably not. However, you will often use terms relating to OSI. Also, the ICND1 exam covers the basics of OSI, so this chapter also covers OSI to prepare you for questions about it on the exam.

Overview of the TCP/IP Networking Model

The TCP/IP model both defines and references a large collection of protocols that allow computers to communicate. To define a protocol, TCP/IP uses documents called Requests for Comments (RFC). (You can find these RFCs using any online search engine.) The TCP/IP model also avoids repeating work already done by some other standards body or vendor consortium by simply referring to standards or protocols created by those groups. For example, the Institute of Electrical and Electronic Engineers (IEEE) defines Ethernet LANs; the TCP/IP model does not define Ethernet in RFCs, but refers to IEEE Ethernet as an option.

An easy comparison can be made between telephones and computers that use TCP/IP. You go to the store and buy a phone from one of a dozen different vendors. When you get home and plug in the phone to the same cable in which your old phone was connected, the new phone works. The phone vendors know the standards for phones in their country and build their phones to match those standards.

Similarly, when you buy a new computer today, it implements the TCP/IP model to the point that you can usually take the computer out of the box, plug in all the right cables, turn it on, and it connects to the network. You can use a web browser to connect to your favorite website. How? Well, the OS on the computer implements parts of the TCP/IP model. The Ethernet card, or wireless LAN card, built into the computer implements some LAN standards referenced by the TCP/IP model. In short, the vendors that created the hardware and software implemented TCP/IP.

To help people understand a networking model, each model breaks the functions into a small number of categories called *layers*. Each layer includes protocols and standards that relate to that category of functions. TCP/IP actually has two alternative models, as shown in Figure 1-4.

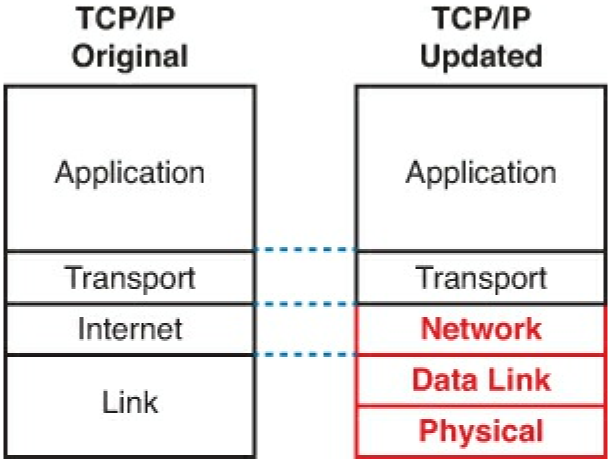


Figure 1-4. Two TCP/IP Networking Models

The model on the left shows the original TCP/IP model listed in RFC 1122, which breaks TCP/IP into four layers. The top two layers focus more on the applications that need to send and receive data. The bottom layer focuses on how to transmit bits over each individual link, with the internet layer focusing on delivering data over the entire path from the original sending computer to the final destination computer.

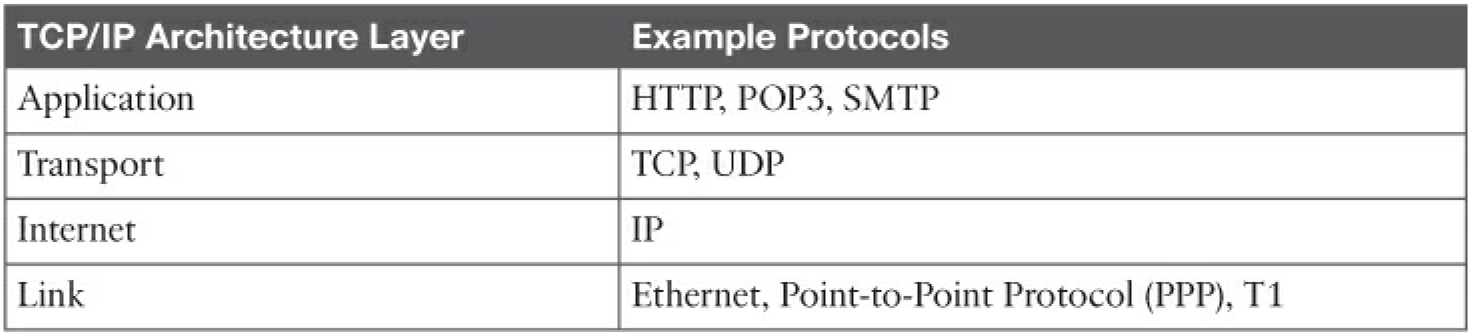
The TCP/IP model on the right is a common method used today to refer to the layers formed by expanding the original model’s link layer on the left into two separate layers: data link and physical (similar to the lower two layers of the OSI model). Note that the model on the right is used more often today.

Note

The original TCP/IP model’s link layer has also been referred to as the *network access* and *network interface* layer.

Many of you will have already heard of several TCP/IP protocols, like the examples listed in Table 1-2. Most of the protocols and standards in this table will be explained in more detail as you work through this book. Following the table, this section takes a closer look at the layers of the TCP/IP model.

Table 1-2. TCP/IP Architectural Model and Example Protocols



TCP/IP Architecture Layer	Example Protocols
Application	HTTP, POP3, SMTP
Transport	TCP, UDP
Internet	IP
Link	Ethernet, Point-to-Point Protocol (PPP), T1

TCP/IP Application Layer

TCP/IP application layer protocols provide services to the application software running on a computer. The application layer does not define the application itself, but it defines services that applications need. For example, application protocol HTTP defines how web browsers can pull the contents of a web page from a web server. In short, the application layer provides an interface between software running on a computer and the network itself.

Arguably, the most popular TCP/IP application today is the web browser. Many major software vendors either have already changed or are changing their application software to support access from a web browser. And thankfully, using a web browser is easy: You start a web browser on your computer and select a website by typing the name of the website, and the web page appears.

HTTP Overview

What really happens to allow that web page to appear on your web browser?

Imagine that Bob opens his browser. His browser has been configured to automatically ask for web server Larry's default web page, or *home page*. The general logic looks like Figure 1-5.

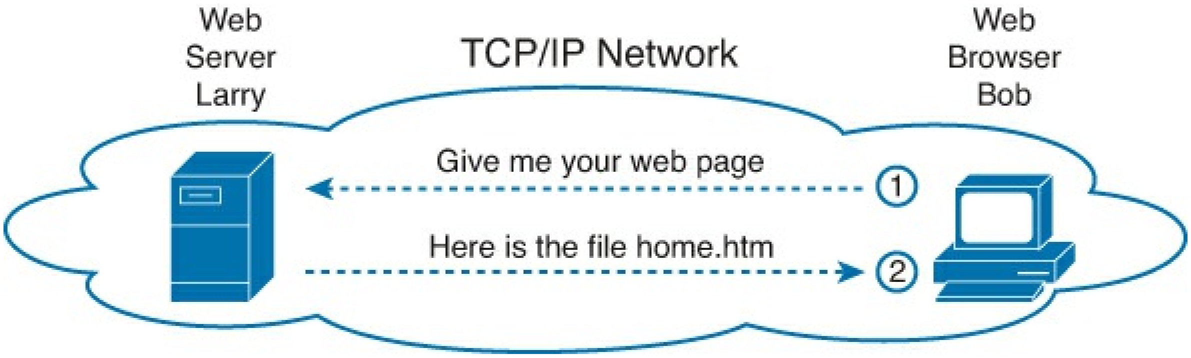


Figure 1-5. Basic Application Logic to Get a Web Page

So, what really happened? Bob's initial request actually asks Larry to send his home page back to Bob. Larry's web server software has been configured to know that the default web page is contained in a file called home.htm. Bob receives the file from Larry and displays the contents of the file in Bob's web-browser window.

HTTP Protocol Mechanisms

Taking a closer look, this example shows how applications on each endpoint computer—specifically, the web-browser application and web-server application—use a TCP/IP application layer protocol. To make the request for a web page and return the contents of the web page, the applications use the Hypertext Transfer Protocol (HTTP).

HTTP did not exist until Tim Berners-Lee created the first web browser and web server in the early 1990s. Berners-Lee gave HTTP functions to ask for the contents of web pages, specifically by giving the web browser the ability to request files from the server, and giving the server a way to return the content of those files. The overall logic matches what was shown in Figure 1-5; Figure 1-6 shows the same idea, but with details specific to HTTP.

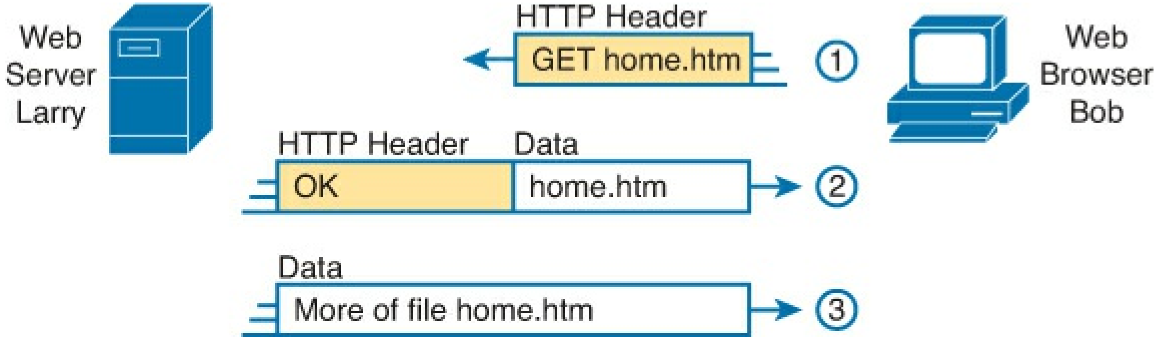


Figure 1-6. HTTP Get Request, HTTP Reply, and One Data-Only Message

Note

The full version of most web addresses—also called Uniform Resource Locators (URL)—begins with the letters "http," which means that HTTP is used to transfer the web pages.

To get the web page from Larry, at Step 1, Bob sends a message with an HTTP header. Generally, protocols use headers as a place to put information used by that protocol. This HTTP header includes the request to "get" a file. The request typically contains the name of the file (home.htm, in this case), or if no filename is mentioned, the web server assumes that Bob wants the default web page.

Step 2 in Figure 1-6 shows the response from web server Larry. The message begins with an HTTP header, with a return code (200), which means something as simple as "OK" returned in the header. HTTP also defines other return codes so that the server can tell the browser whether the request worked. (Here is another example: If you ever looked for a web page that was not found, and then received an HTTP 404 "not found" error, you received an HTTP return code of 404.) The second message also includes the first part of the requested file.

Step 3 in Figure 1-6 shows another message from web server Larry to web browser Bob, but this time without an HTTP header. HTTP transfers the data by sending multiple messages, each with a part of the file. Rather than wasting space by sending repeated HTTP headers that list the same information, these additional messages simply omit the header.

TCP/IP Transport Layer

Although many TCP/IP application layer protocols exist, the TCP/IP transport layer includes a smaller number of protocols. The two most commonly used transport layer protocols are the *Transmission Control Protocol (TCP)* and the *User Datagram Protocol (UDP)*.

Transport layer protocols provide services to the application layer protocols that reside one layer higher in the TCP/IP model. How does a transport layer protocol provide a service to a higher-layer protocol? This section introduces that general concept by focusing on a single service provided by TCP: error recovery. Later chapters examine the transport layer in more detail, and discuss more functions of the transport layer.

TCP Error Recovery Basics

To appreciate what the transport layer protocols do, you must think about the layer above the transport layer, the application layer. Why? Well, each layer provides a service to the layer above it, like the error-recovery service provided to application layer protocols by TCP.

For example, in Figure 1-5, Bob and Larry used HTTP to transfer the home page from web server Larry to Bob's web browser. But what would have happened if Bob's HTTP GET request had been lost in transit through the TCP/IP network? Or, what would have happened if Larry's response, which included the contents of the home page, had been lost? Well, as you might expect, in either case, the page would not have shown up in Bob's browser.

TCP/IP needs a mechanism to guarantee delivery of data across a network. Because many application layer protocols probably want a way to guarantee delivery of data across a network, the creators of TCP included an error-recovery feature. To recover from errors, TCP uses the concept of acknowledgments. Figure 1-7 outlines the basic idea behind how TCP notices lost data and asks the sender to try again.

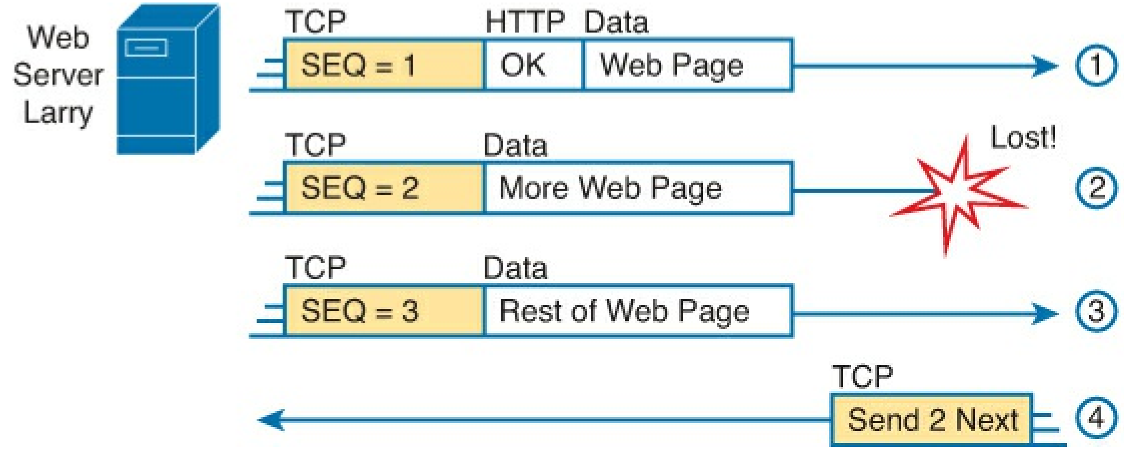


Figure 1-7. TCP Error-Recovery Services as Provided to HTTP

Figure 1-7 shows web server Larry sending a web page to web browser Bob, using three separate messages. Note that this figure shows the same HTTP headers as Figure 1-6, but it also shows a TCP header. The TCP header shows a sequence number (SEQ) with each message. In this example, the network has a problem, and the network fails to deliver the TCP message (called a segment) with sequence number 2. When Bob receives messages with sequence numbers 1 and 3, but does not receive a message with sequence number 2, Bob realizes that message 2 was lost. That realization by Bob's TCP logic causes Bob to send a TCP segment back to Larry, asking Larry to send message 2 again.

Same-Layer and Adjacent-Layer Interactions

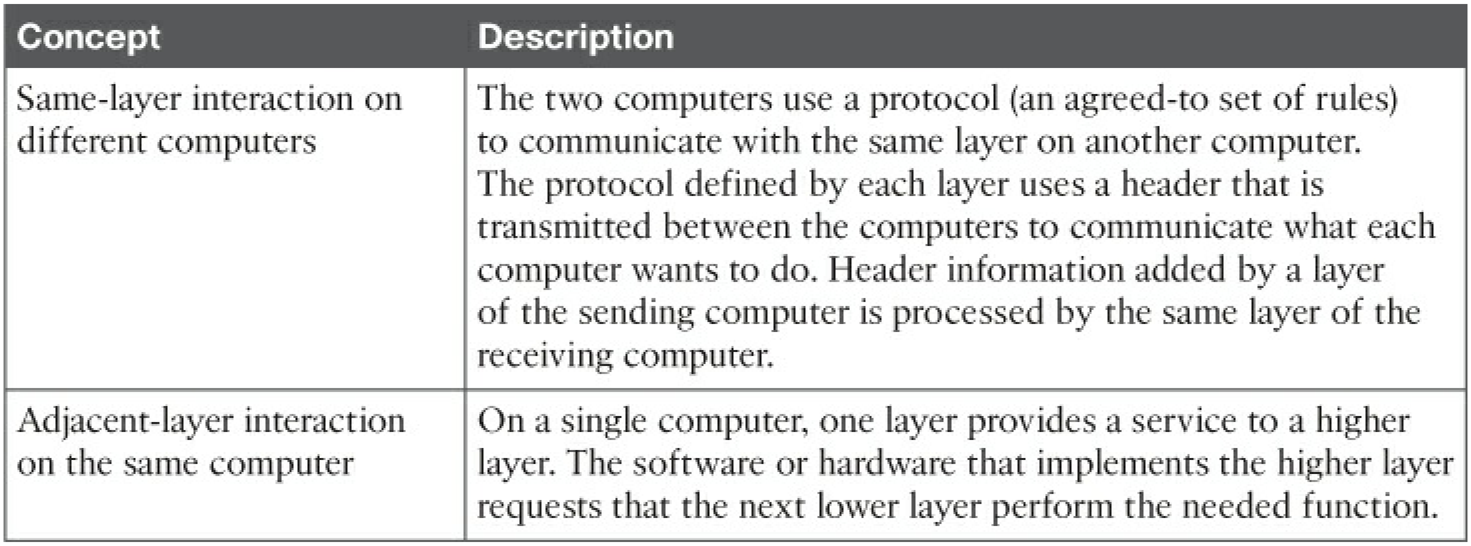
The example in Figure 1-7 also demonstrates a function called *adjacent-layer interaction*, which refers to the concepts of how adjacent layers in a networking model, on the same computer, work together. In this example, the higher-layer protocol (HTTP) wants error recovery, and the higher layer uses the next lower-layer protocol (TCP) to perform the service of error recovery; the lower layer provides a service to the layer above it.

Figure 1-7 also shows an example of a similar function called *same-layer interaction.* When a particular layer on one computer wants to communicate with the same layer on another computer, the two computers use headers to hold the information that they want to communicate. For example, in Figure 1-7, Larry set the sequence numbers to 1, 2, and 3 so that Bob could notice when some of the data did not arrive. Larry's TCP process created that TCP header with the sequence number; Bob's TCP process received and reacted to the TCP segments. This process through which two computers set and interpret the information in the header used by that layer is called *same-layer interaction*, and it occurs between computers that are communicating over a network.

Table 1-3 summarizes the key points about how adjacent layers work together on a single computer and how one layer on one computer works with the same networking layer on another computer.

Key Topic

Table 1-3. Summary: Same-Layer and Adjacent-Layer Interactions



Concept	Description
Same-layer interaction on different computers	The two computers use a protocol (an agreed-to set of rules) to communicate with the same layer on another computer. The protocol defined by each layer uses a header that is transmitted between the computers to communicate what each computer wants to do. Header information added by a layer of the sending computer is processed by the same layer of the receiving computer.
Adjacent-layer interaction on the same computer	On a single computer, one layer provides a service to a higher layer. The software or hardware that implements the higher layer requests that the next lower layer perform the needed function.

TCP/IP Network Layer

The application layer includes many protocols. The transport layer includes fewer, most notably, TCP and UDP. The TCP/IP network layer includes a small number of protocols, but only one major protocol: the *Internet Protocol (IP)*. In fact, the name *TCP/IP* is simply the names of the two most common protocols (TCP and IP) separated by a /.

IP provides several features, most importantly, addressing and routing. This section begins by comparing IP's addressing and routing with another commonly known system that uses addressing and routing: the postal service. Following that, this section introduces IP addressing and routing. (More details follow in Chapter 4, "Fundamentals of IPv4 Addressing and Routing.")

Internet Protocol and the Postal Service

Imagine that you just wrote two letters: one to a friend on the other side of the country and one to a friend on the other side of town. You addressed the envelopes and put on the stamps, so both are ready to give to the postal service. Is there much difference in how you treat each letter? Not really. Typically, you would just put them in the same mailbox and expect the postal service to deliver both letters.

The postal service, however, must think about each letter separately, and then make a decision of where to send each letter so that it is delivered. For the letter sent across town, the people in the local post office probably just need to put the letter on another truck.

For the letter that needs to go across the country, the postal service sends the letter to another post office, then another, and so on, until the letter gets delivered across the country. At each post office, the postal service must process the letter and choose where to send it next.

To make it all work, the postal service has regular routes for small trucks, large trucks, planes, boats, and so on, to move letters between postal service sites. The service must be able to receive and forward the letters, and it must make good decisions about where to send each letter next, as shown in Figure 1-8.

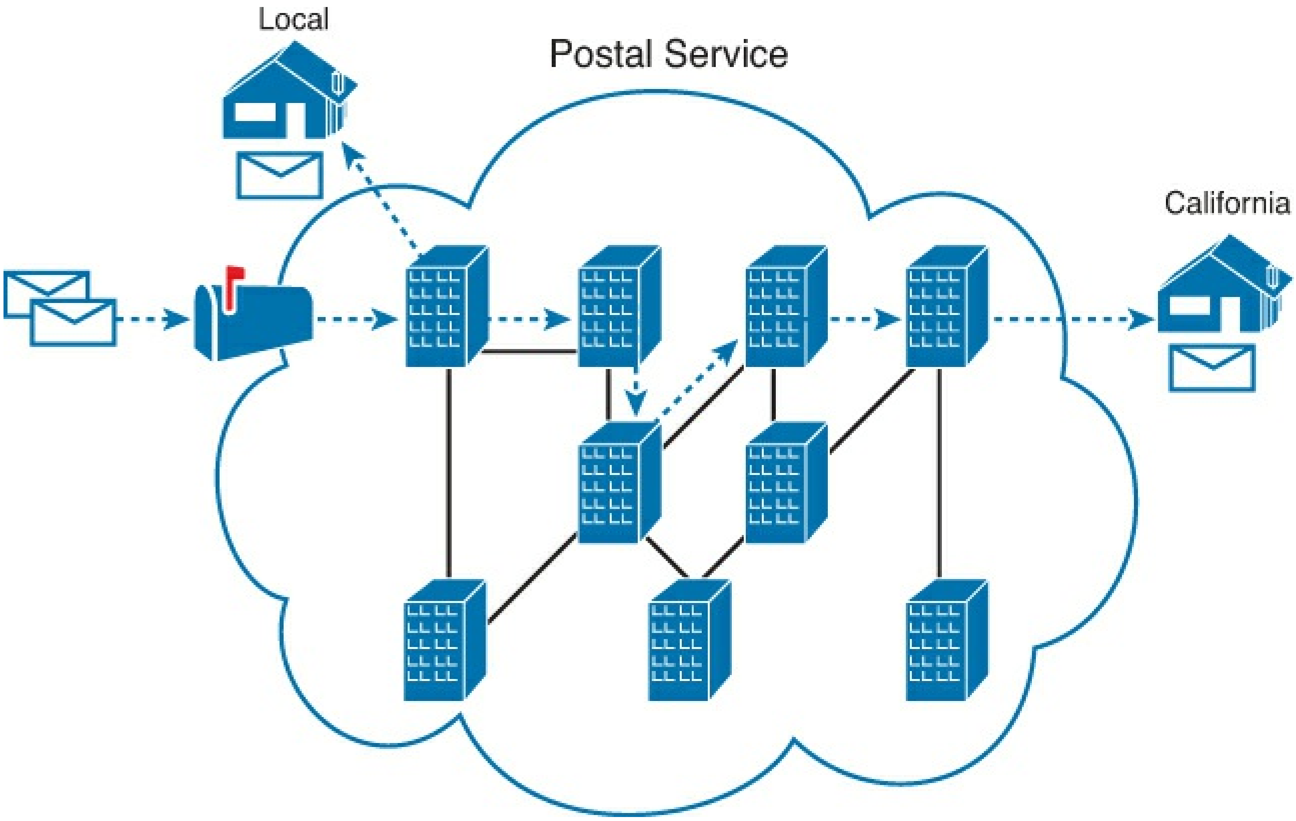


Figure 1-8. Postal Service Forwarding (Routing) Letters

Still thinking about the postal service, consider the difference between the person sending the letter and the work that the postal service does. The person sending the letters expects that the postal service will deliver the letter most of the time. However, the person sending the letter does not need to know the details of exactly what path the letters take. In contrast, the postal service does not create the letter, but they accept the letter from the customer. Then, the postal service must know the details about addresses and postal codes that group addresses into larger groups, and it must have the ability to deliver the letters.

The TCP/IP application and transport layers act like the person sending letters through the postal service. These upper layers work the same way regardless of whether the endpoint host computers are on the same LAN or are separated by the entire Internet. To send a message, these upper layers ask the layer below them, the network layer, to deliver the message.

The lower layers of the TCP/IP model act more like the postal service to deliver those messages to the correct destinations. To do so, these lower layers must understand the underlying physical network because they must choose how to best deliver the data from one host to another.

So, what does this all matter to networking? Well, the network layer of the TCP/IP networking model, primarily defined by the *Internet Protocol (IP)*, works much like the postal service. IP defines that each host computer should have a different IP address, just as the postal service defines addressing that allows unique addresses for each house, apartment, and business.

Similarly, IP defines the process of routing so that devices called routers can work like the post office, forwarding packets of data so that they are delivered to the correct destinations. Just as the postal service created the necessary infrastructure to deliver letters—post offices, sorting machines, trucks, planes, and personnel—the network layer defines the details of how a network infrastructure should be created so that the network can deliver data to all computers in the network.

> **Note**
>
> TCP/IP defines two versions of IP: IP Version 4 (IPv4) and IP Version 6 (IPv6). The world still mostly uses IPv4, so this introductory part of the book uses IPv4 for all references to IP. Later in this book, Part VII, "IP Version 6," discusses this newer version of the IP protocol.

Internet Protocol Addressing Basics

IP defines addresses for several important reasons. First, each device that uses TCP/IP—each TCP/IP *host*—needs a unique address so that it can be identified in the network. IP also defines how to group addresses together, just like the postal system groups addresses based on postal codes (like ZIP codes in the United States).

To understand the basics, examine Figure 1-9, which shows the familiar web server Larry and web browser Bob; but now, instead of ignoring the network between these two computers, part of the network infrastructure is included.

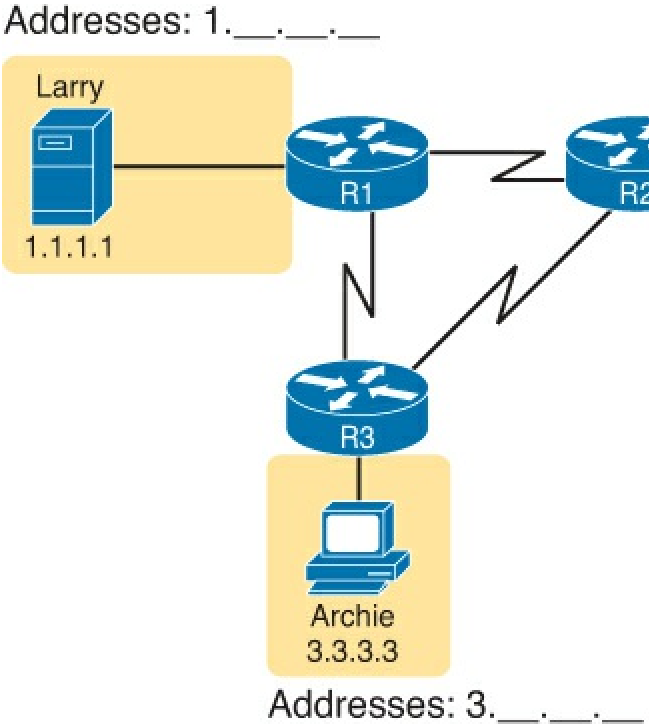


Figure 1-9. Simple TCP/IP Network: Three Routers with IP Addresses Grouped

First, note that Figure 1-9 shows some sample IP addresses. Each IP address has four numbers, separated by periods. In this case, Larry uses IP address 1.1.1.1, and Bob uses 2.2.2.2. This style of number is called a *dotted-decimal notation (DDN)*.

Figure 1-9 also shows three groups of address. In this example, all IP address that begin with 1 must be on the upper left, as shown in shorthand in the figure as 1._._._. All addresses that begin with 2 must be on the right, as shown in shorthand as 2._._._. Finally, all IP addresses that begin with 3 must be at the bottom of the figure.

Additionally, Figure 1-9 also introduces icons that represent IP routers. Routers are networking devices that connect the parts of the TCP/IP network together for the purpose of routing (forwarding) IP packets to the correct destination. Routers do the equivalent of the work done by each post office site: They receive IP packets on various physical interfaces, make decisions based on the IP address included with the packet, and then physically forward the packet out some other network interface.

IP Routing Basics

The TCP/IP network layer, using the IP protocol, provides a service of forwarding IP packets from one device to another. Any device with an IP address can connect to the TCP/IP network and send packets. This section shows a basic IP routing example for perspective.

> **Note**
>
> The term *IP host* refers to any device, regardless of size or power, that has an IP address and connects to any TCP/IP network.

Figure 1-10 repeats the familiar case in which web server Larry wants to send part of a web page to Bob, but now with details related to IP. On the lower left, note that server Larry has the familiar application data, HTTP header, and TCP header ready to send. Additionally, the message now also contains an IP header. The IP header includes a source IP address of Larry's IP address (1.1.1.1) and a destination IP address of Bob's IP address (2.2.2.2).

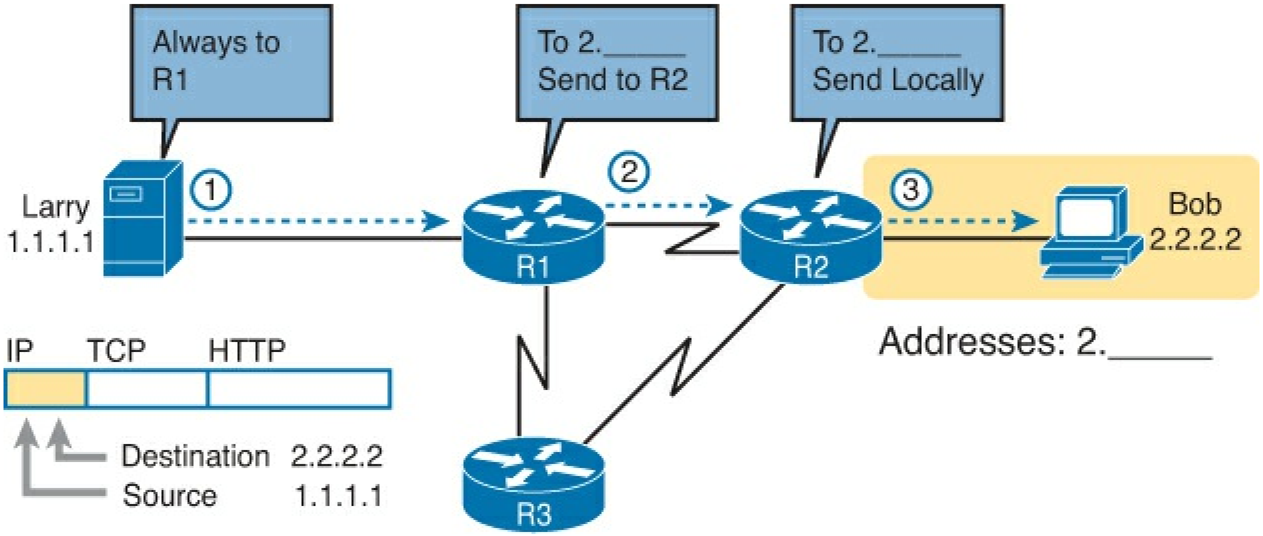


Figure 1-10. Basic Routing Example

Step 1, on the left of Figure 1-10, begins with Larry being ready to send an IP packet. Larry's IP process chooses to send the packet to some router—a nearby router on the same LAN—with the expectation that the router will know how to forward the packet. (This logic is much like you or me sending all our letters by putting them in a nearby post office box.) Larry doesn't need to know anything more about the topology or the other routers.

At Step 2, router R1 receives the IP packet, and R1's IP process makes a decision. R1 looks at the destination address (2.2.2.2), compares that address to its known IP routes, and chooses to forward the packet to router R2. This process of forwarding the IP packet is called *IP routing* (or simply *routing*).

At Step 3, router R2 repeats the same kind of logic used by router R1. R2's IP process will compare the packet's destination IP address (2.2.2.2) to R2's known IP routes and make a choice to forward the packet to the right, on to Bob.

All the CCNA exams cover IP fairly deeply. Practically half the chapters in this book discuss some feature that relates to addressing, IP routing, and how routers perform routing.

TCP/IP Link Layer (Data Link Plus Physical)

The TCP/IP model's original link layer defines the protocols and hardware required to deliver data across some physical network. The term *link* refers to the physical connections, or links, between two devices and the protocols used to control those links.

Just like every layer in any networking model, the TCP/IP link layer provides services to the layer above it in the model. When a host's or router's IP process chooses to send an IP packet to another router or host, that host or router then uses link-layer details to send that packet to the next host/router.

Because each layer provides a service to the layer above it, take a moment to think about the IP logic related to Figure 1-10. In that example, host Larry's IP logic chooses to send the IP packet to a nearby router (R1), with no mention of the underlying Ethernet. The Ethernet network, which implements link-layer protocols, must then be used to deliver that packet from host Larry over to router R1. Figure 1-11 shows four steps of what occurs at the link layer to allow Larry to send the IP packet to R1.

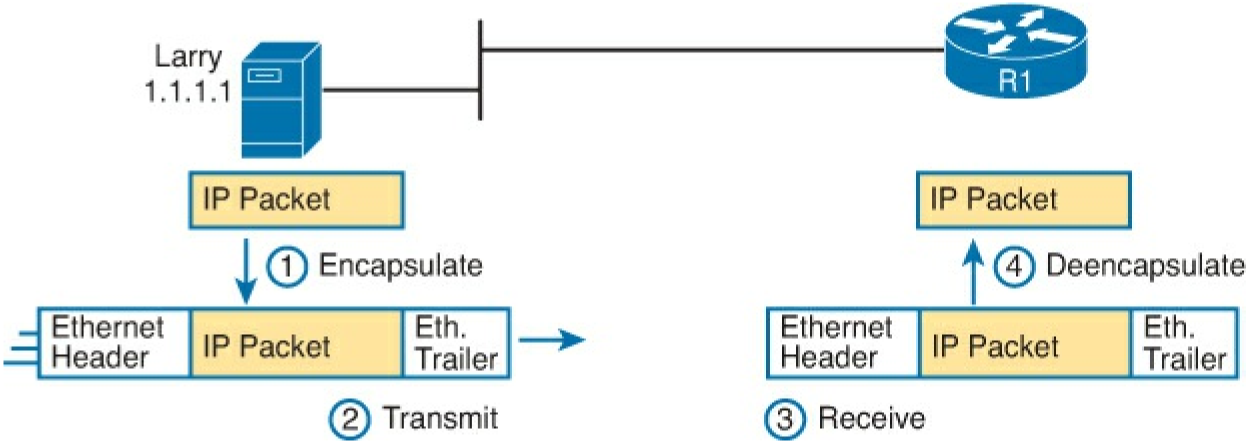


Figure 1-11. Larry Using Ethernet to Forward an IP Packet to Router R1

Note

Figure 1-11 depicts the Ethernet as a series of lines. Networking diagrams often use this convention when drawing Ethernet LANs, in cases where the actual LAN cabling and LAN devices are not important to some discussion, as is the case here. The LAN would have cables and devices, like LAN switches, which are not shown in this figure.

Figure 1-11 shows four steps. The first two occur on Larry, and the last two occur on router R1, as follows:

Step 1. Larry encapsulates the IP packet between an Ethernet header and Ethernet trailer, creating an Ethernet *frame*.

Step 2. Larry physically transmits the bits of this Ethernet frame, using electricity flowing over the Ethernet cabling.

Step 3. Router R1 physically receives the electrical signal over a cable, and re-creates the same bits by interpreting the meaning of the electrical signals.

Step 4. Router R1 deencapsulates the IP packet from the Ethernet frame by removing and discarding the Ethernet header and trailer.

By the end of this process, the link-layer processes on Larry and R1 have worked together to deliver the packet from Larry to router R1.

Note

Protocols define both headers and trailers for the same general reason, but headers exist at the beginning of the message and trailers exist at the end.

The link layer includes a large number of protocols and standards. For example, the link layer includes all the variations of Ethernet protocols, along with several other LAN standards that were more popular in decades past. The link layer includes wide-area network (WAN) standards for different physical media, which differ significantly compared to LAN standards because of the longer distances involved in transmitting the data. This layer also includes the popular WAN standards that add headers and trailers as shown generally in Figure 1-11—protocols such as the Point-to-Point Protocol (PPP) and Frame Relay. Chapter 2, "Fundamentals of Ethernet LANs," and Chapter 3, "Fundamentals of WANs," further develop these topics for LANs and WANs, respectively.

In short, the TCP/IP link layer includes two distinct functions: functions related to the physical transmission of the data, plus the protocols and rules that control the use of the physical media. The five-layer TCP/IP model simply splits out the link layer into two layers (data link and physical) to match this logic.

TCP/IP Model and Terminology

Before completing this introduction to the TCP/IP model, this section examines a few remaining details of the model and some related terminology.

Comparing the Original and Modern TCP/IP Models

The original TCP/IP model defined a single layer—the link layer—below the internetwork layer. The functions defined in the original link layer can be broken into two major categories: functions related directly to the physical transmission of data and those only indirectly related to the physical transmission of data. For example, in the four steps shown in Figure 1-11, Steps 2 and 3 were specific to sending the data, but Steps 1 and 4—encapsulation and deencapsulation—were only indirectly related. This division will become clearer as you read about additional details of each protocol and standard.

Today, most documents use a more modern version of the TCP/IP model, as shown in Figure 1-12. Comparing the two, the upper layers are identical, except a name change from "internet" to "network." The lower layers differ in that the single link layer in the original model is split into two layers to match the division of physical transmission details from the other functions. Figure 1-12 shows the two versions of the TCP/IP model again, with emphasis on these distinctions.

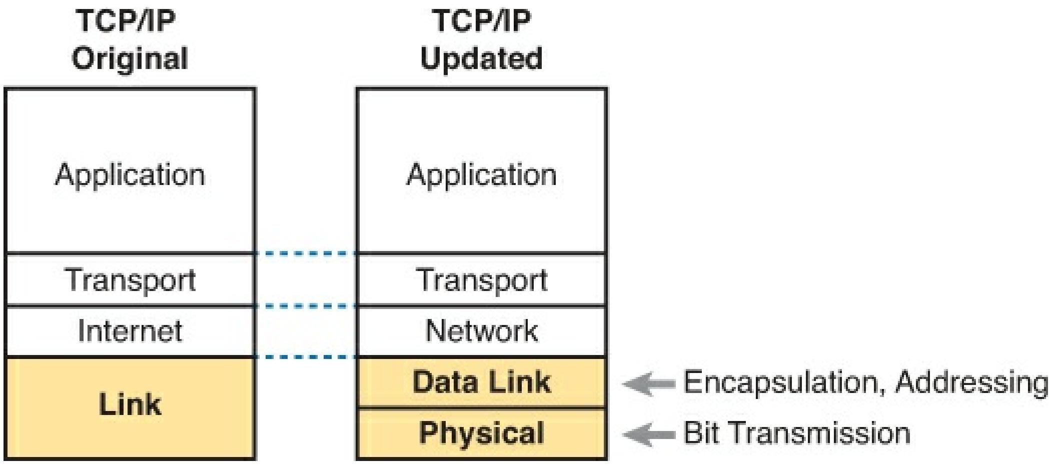

TCP/IP Original
TCP/IP Updated
Application
Application
Transport
Transport
Internet
Network
Link
Data Link
Physical
Encapsulation, Addressing
Bit Transmission

Figure 1-12. Link Versus Data Link and Physical Layers

Data Encapsulation Terminology

As you can see from the explanations of how HTTP, TCP, IP, and Ethernet do their jobs, each layer adds its own header (and for data-link protocols, also a trailer) to the data supplied by the higher layer. The term *encapsulation* refers to the process of putting headers (and sometimes trailers) around some data.

Many of the examples in this chapter show the encapsulation process. For example, web server Larry encapsulated the contents of the home page inside an HTTP header in Figure 1-6. The TCP layer encapsulated the HTTP headers and data inside a TCP header in Figure 1-7. IP encapsulated the TCP headers and the data inside an IP header in Figure 1-10. Finally, the Ethernet link layer encapsulated the IP packets inside both a header and a trailer in Figure 1-11.

The process by which a TCP/IP host sends data can be viewed as a five-step process. The first four steps relate to the encapsulation performed by the four TCP/IP layers, and the last step is the actual physical transmission of the data by the host. In fact, if you use the five-layer TCP/IP model, one step corresponds to the role of each layer. The steps are summarized in the following list:

- **Step 1. Create and encapsulate the application data with any required application layer headers.** For example, the HTTP OK message can be returned in an HTTP header, followed by part of the contents of a web page.
- **Step 2. Encapsulate the data supplied by the application layer inside a transport layer header.** For end-user applications, a TCP or UDP header is typically used.
- **Step 3. Encapsulate the data supplied by the transport layer inside a network layer (IP) header.** IP defines the IP addresses that uniquely identify each computer.
- **Step 4. Encapsulate the data supplied by the network layer inside a data link layer header and trailer.** This layer uses both a header and a trailer.
- **Step 5. Transmit the bits.** The physical layer encodes a signal onto the medium to transmit the frame.

The numbers in Figure 1-13 correspond to the five steps in this list, graphically showing the same concepts. Note that because the application layer often does not need to add a header, the figure does not show a specific application layer header.

Key Topic

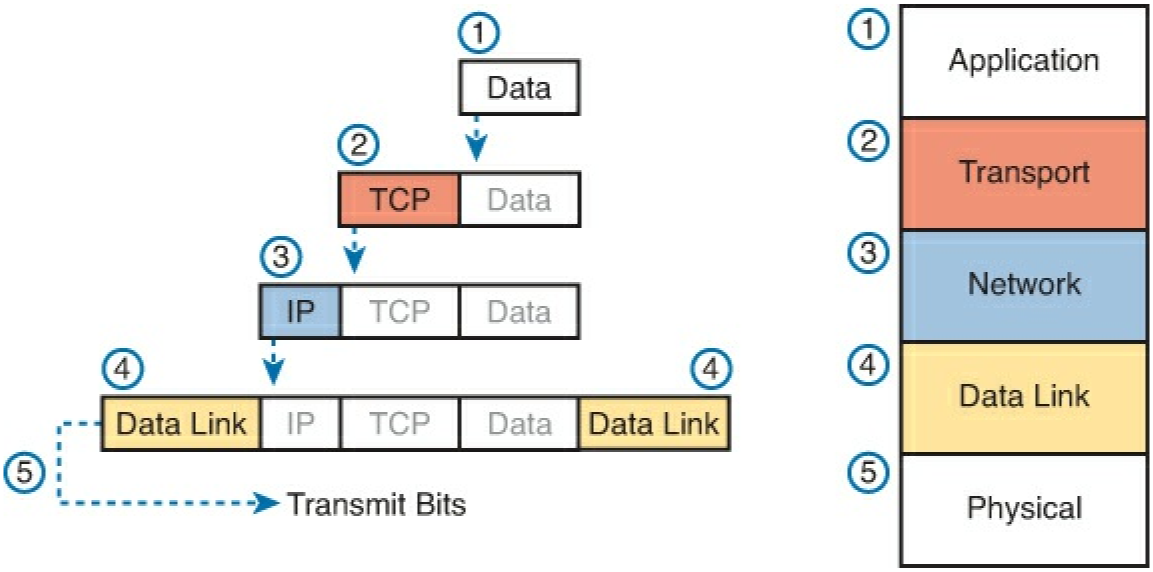

①
Data
②
TCP
Data
③
IP
TCP
Data
④
Data Link
IP
TCP
Data
Data Link
④
⑤
Transmit Bits
① Application
② Transport
③ Network
④ Data Link
⑤ Physical

Figure 1-13. Five Steps of Data Encapsulation: TCP/IP

Names of TCP/IP Messages

Finally, take particular care to remember the terms *segment*, *packet*, and *frame* and the meaning of each. Each term refers to the headers (and possibly trailers) defined by a particular layer and the data encapsulated following that header. Each term, however, refers to a different layer: segment for the transport layer, packet for the network layer, and frame for the link layer. Figure 1-14 shows each layer along with the associated term.

Key Topic

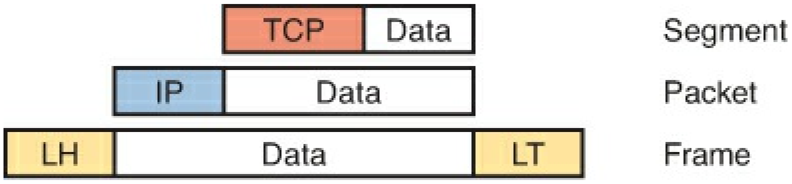


Figure 1-14. Perspectives on Encapsulation and “Data”*

* The letters LH and LT stand for link header and link trailer, respectively, and refer to the data link layer header and trailer.

Figure 1-14 also shows the encapsulated data as simply “data.” When focusing on the work done by a particular layer, the encapsulated data typically is unimportant. For example, an IP packet can indeed have a TCP header after the IP header, an HTTP header after the TCP header, and data for a web page after the HTTP header. However, when discussing IP, you probably just care about the IP header, so everything after the IP header is just called “data.” So, when drawing IP packets, everything after the IP header is typically shown simply as “data.”

OSI Networking Model

At one point in the history of the OSI model, many people thought that OSI would win the battle of the networking models discussed earlier. If that had occurred, instead of running TCP/IP on every computer in the world, those computers would be running with OSI.

However, OSI did not win that battle. In fact, OSI no longer exists as a networking model that could be used instead of TCP/IP, although some of the original protocols referenced by the OSI model still exist.

So, why is OSI even in this book? Terminology. During those years in which many people thought the OSI model would become commonplace in the world of networking (mostly in the late 1980s and early 1990s), many vendors and protocol documents started using terminology from the OSI model. That terminology remains today. So, while you will never need to work with a computer that uses OSI, to understand modern networking terminology, you need to understand something about OSI.

Comparing OSI and TCP/IP

The OSI model has many similarities to the TCP/IP model from a basic conceptual perspective. It has (seven) layers, and each layer defines a set of typical networking functions. As with TCP/IP, the OSI layers each refer to multiple protocols and standards that implement the functions specified by each layer. In other cases, just as for TCP/IP, the OSI committees did not create new protocols or standards, but instead referenced other protocols that were already defined. For example, the IEEE defines Ethernet standards, so the OSI committees did not waste time specifying a new type of Ethernet; it simply referred to the IEEE Ethernet standards.

Today, the OSI model can be used as a standard of comparison to other networking models. Figure 1-15 compares the seven-layer OSI model with both the four-layer and five-layer TCP/IP models.

Key Topic

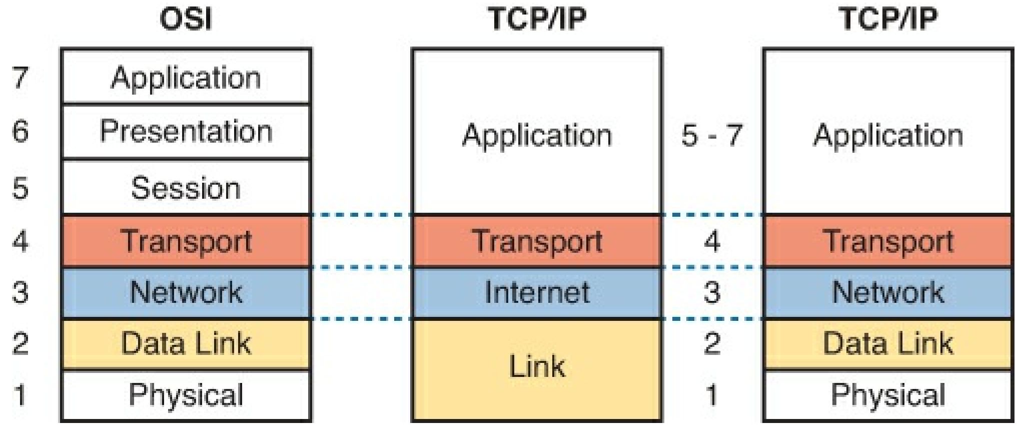


Figure 1-15. OSI Model Compared to the Two TCP/IP Models

Next, this section will examine two ways in which we still use OSI terminology today: to describe other protocols and to describe the encapsulation process. Along the way, the text will briefly examine each layer of the OSI model.

Describing Protocols by Referencing the OSI Layers

Even today, networking documents often describe TCP/IP protocols and standards by referencing OSI layers, both by layer number and layer name. For example, a common description of a LAN switch is "layer 2 switch," with "layer 2" referring to OSI layer 2. Because OSI did have a well-defined set of functions associated with each of its seven layers, if you know those functions, you can understand what people mean when they refer to a product or function by its OSI layer.

For another example, TCP/IP's original internet layer, as implemented mainly by IP, equates most directly to the OSI *network* layer. So, most people say that IP is a *network layer protocol*, or a *Layer 3 protocol*, using OSI terminology and numbers for the layer. Of course, if you numbered the TCP/IP model, starting at the bottom, IP would be either Layer 2 or 3, depending on what version of the TCP/IP model you care to use. However, even though IP is a TCP/IP protocol, everyone uses the OSI model layer names and numbers when describing IP or any other protocol for that matter.

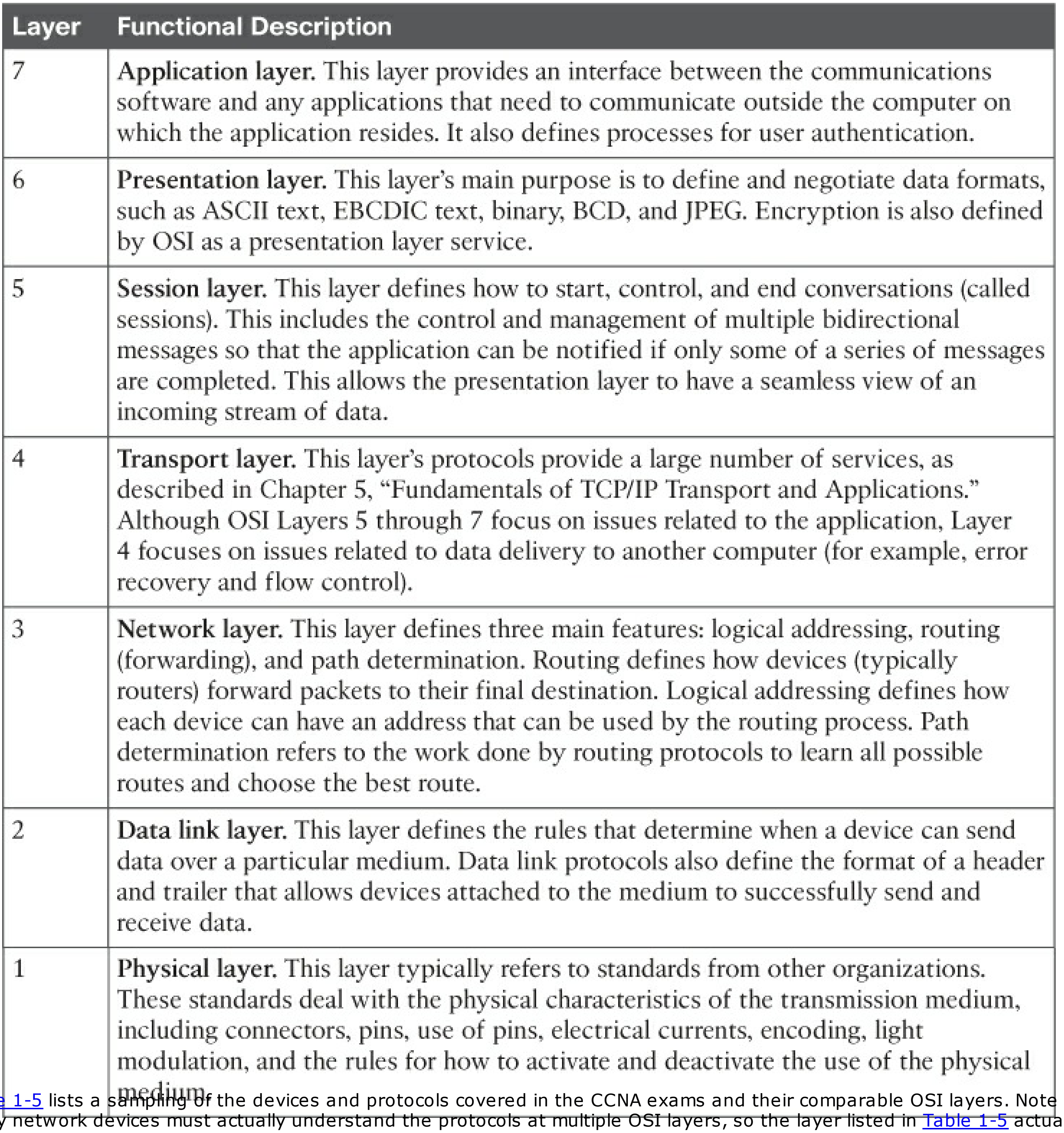
The claim that a particular TCP/IP layer is similar to a particular OSI layer is a general comparison, but not a detailed comparison. The comparison is a little like comparing a car to a truck: Both can get you from point A to point B, but they have many specific differences, like the truck having a truck bed in which to carry cargo. Similarly, both the OSI and TCP/IP network layers define logical addressing and routing. However, the addresses have a different size, and the routing logic even works differently. So the comparison of OSI layers to other protocol models is a general comparison of major goals, and not a comparison of the specific methods.

OSI Layers and Their Functions

Cisco requires that CCENTs demonstrate a basic understanding of the functions defined by each OSI layer, as well as remember the names of the layers. It is also important that, for each device or protocol referenced throughout the book, you understand which layers of the OSI model most closely match the functions defined by that device or protocol.

Today, because most people happen to be much more familiar with TCP/IP functions than with OSI functions, one of the best ways to learn about the function of different OSI layers is to think about the functions in the TCP/IP model and to correlate those with the OSI model. If you use the five-layer TCP/IP model, the bottom four layers of OSI and TCP/IP map closely together. The only difference in these bottom four layers is the name of OSI Layer 3 (network) compared to the original TCP/IP model (internet). The upper three layers of the OSI reference model (application, presentation, and session—Layers 7, 6, and 5) define functions that all map to the TCP/IP application layer. Table 1-4 defines the functions of the seven layers.

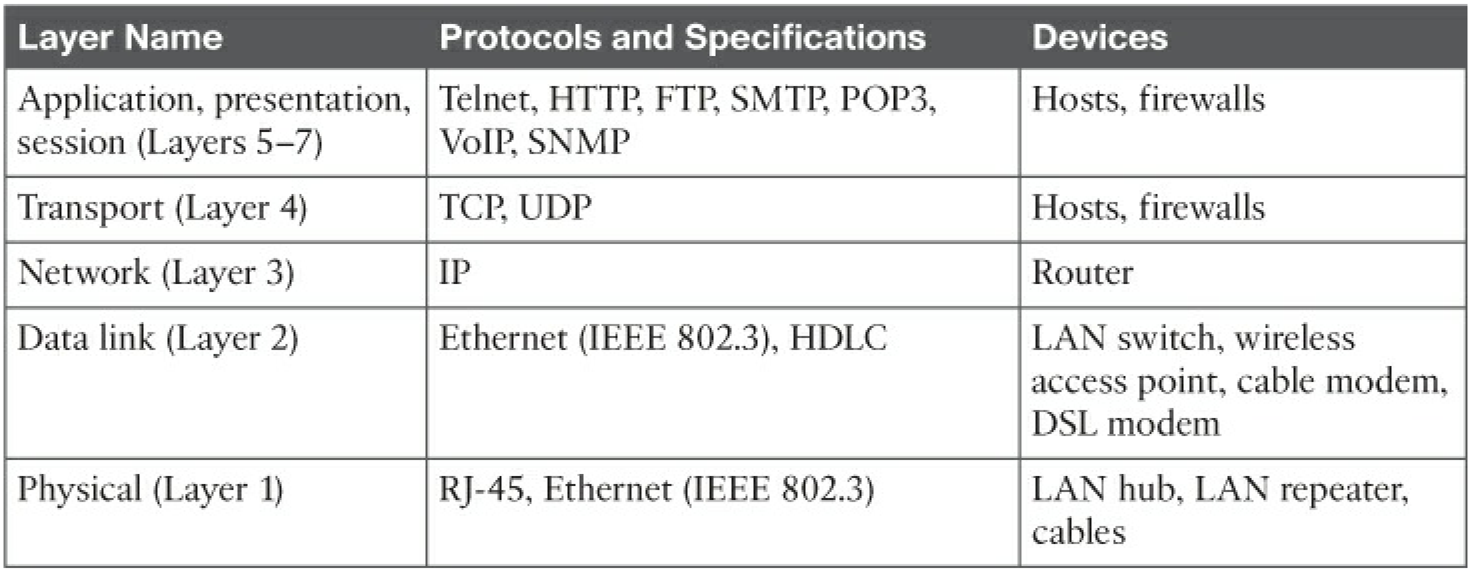
Table 1-4. OSI Reference Model Layer Definitions



Layer	Functional Description
7	**Application layer.** This layer provides an interface between the communications software and any applications that need to communicate outside the computer on which the application resides. It also defines processes for user authentication.
6	**Presentation layer.** This layer's main purpose is to define and negotiate data formats, such as ASCII text, EBCDIC text, binary, BCD, and JPEG. Encryption is also defined by OSI as a presentation layer service.
5	**Session layer.** This layer defines how to start, control, and end conversations (called sessions). This includes the control and management of multiple bidirectional messages so that the application can be notified if only some of a series of messages are completed. This allows the presentation layer to have a seamless view of an incoming stream of data.
4	**Transport layer.** This layer's protocols provide a large number of services, as described in Chapter 5, "Fundamentals of TCP/IP Transport and Applications." Although OSI Layers 5 through 7 focus on issues related to the application, Layer 4 focuses on issues related to data delivery to another computer (for example, error recovery and flow control).
3	**Network layer.** This layer defines three main features: logical addressing, routing (forwarding), and path determination. Routing defines how devices (typically routers) forward packets to their final destination. Logical addressing defines how each device can have an address that can be used by the routing process. Path determination refers to the work done by routing protocols to learn all possible routes and choose the best route.
2	**Data link layer.** This layer defines the rules that determine when a device can send data over a particular medium. Data link protocols also define the format of a header and trailer that allows devices attached to the medium to successfully send and receive data.
1	**Physical layer.** This layer typically refers to standards from other organizations. These standards deal with the physical characteristics of the transmission medium, including connectors, pins, use of pins, electrical currents, encoding, light modulation, and the rules for how to activate and deactivate the use of the physical medium.

Table 1-5 lists a sampling of the devices and protocols covered in the CCNA exams and their comparable OSI layers. Note that many network devices must actually understand the protocols at multiple OSI layers, so the layer listed in Table 1-5 actually refers to the highest layer that the device normally thinks about when performing its core work. For example, routers need to think about Layer 3 concepts, but they must also support features at both Layers 1 and 2.

Table 1-5. OSI Reference Model—Example Devices and Protocols



Layer Name	Protocols and Specifications	Devices
Application, presentation, session (Layers 5–7)	Telnet, HTTP, FTP, SMTP, POP3, VoIP, SNMP	Hosts, firewalls
Transport (Layer 4)	TCP, UDP	Hosts, firewalls
Network (Layer 3)	IP	Router
Data link (Layer 2)	Ethernet (IEEE 802.3), HDLC	LAN switch, wireless access point, cable modem, DSL modem
Physical (Layer 1)	RJ-45, Ethernet (IEEE 802.3)	LAN hub, LAN repeater, cables

Besides remembering the basics of the features of each OSI layer (as in Table 1-4), and some example protocols and devices at each layer (as in Table 1-5), you should also memorize the names of the layers. You can simply memorize them, but some people like to use a mnemonic phrase to make memorization easier. In the following three phrases, the first letter of each word is the same as the first letter of an OSI layer name, in the order specified in parentheses:

- All People Seem To Need Data Processing (Layers 7 to 1)
- Please Do Not Take Sausage Pizzas Away (Layers 1 to 7)
- Pew! Dead Ninja Turtles Smell Particularly Awful (Layers 1 to 7)

OSI Layering Concepts and Benefits

While networking models use layers to help humans categorize and understand the many functions in a network, networking models use layers for many reasons. For example, consider another postal service analogy. A person writing a letter does not have to think about how the postal service will deliver a letter across the country. The postal worker in the middle of the country does not have to worry about the contents of the letter. Likewise, networking models that divide functions into different layers enable one software package or hardware device to implement functions from one layer, and assume that other software/hardware will perform the functions defined by the other layers.

The following list summarizes the benefits of layered protocol specifications:

Key Topic

- **Less complex:** Compared to not using a layered model, network models break the concepts into smaller parts.
- **Standard interfaces:** The standard interface definitions between each layer allow multiple vendors to create products that fill a particular role, with all the benefits of open competition.
- **Easier to learn:** Humans can more easily discuss and learn about the many details of a protocol specification.
- **Easier to develop:** Reduced complexity allows easier program changes and faster product development.
- **Multivendor interoperability:** Creating products to meet the same networking standards means that computers and networking gear from multiple vendors can work in the same network.
- **Modular engineering:** One vendor can write software that implements higher layers—for example, a web browser—and another vendor can write software that implements the lower layers—for example, Microsoft's built-in TCP/IP software in its OSs.

OSI Encapsulation Terminology

Like TCP/IP, each OSI layer asks for services from the next lower layer. To provide the services, each layer makes use of a header and possibly a trailer. The lower layer encapsulates the higher layer's data behind a header. The final topic of this chapter explains some of the terminology and concepts related to OSI encapsulation.

The TCP/IP model uses terms such as *segment*, *packet*, and *frame* to refer to various layers and their respective encapsulated data (refer to Figure 1-13). OSI uses a more generic term: *protocol data unit (PDU)*.

A PDU represents the bits that include the headers and trailers for that layer, as well as the encapsulated data. For example, an IP packet, as shown in Figure 1-14, using OSI terminology, is a PDU. In fact, an IP packet is a *Layer 3 PDU* (abbreviated L3PDU) because IP is a Layer 3 protocol. So, rather than use the terms *segment*, *packet*, or *frame*, OSI simply refers to the "Layer x PDU" (LxPDU), with "x" referring to the number of the layer being discussed.

Figure 1-16 represents the typical encapsulation process, with the top of the figure showing the application data and application layer header and the bottom of the figure showing the L2PDU that is transmitted onto the physical link.

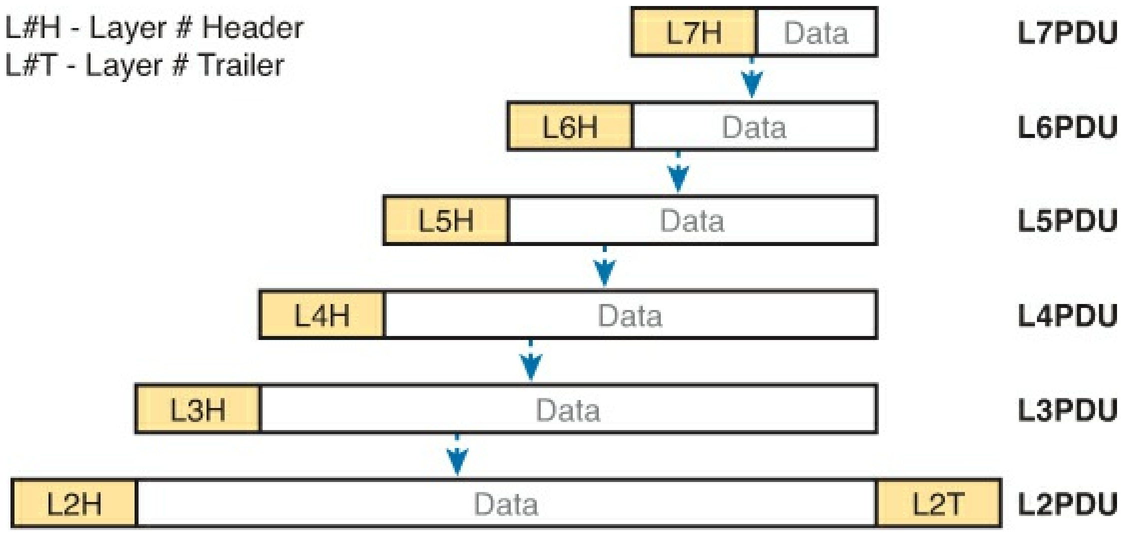

L#H - Layer # Header
L#T - Layer # Trailer
L7H
Data
L7PDU
L6H
Data
L6PDU
L5H
Data
L5PDU
L4H
Data
L4PDU
L3H
Data
L3PDU
L2H
Data
L2T
L2PDU

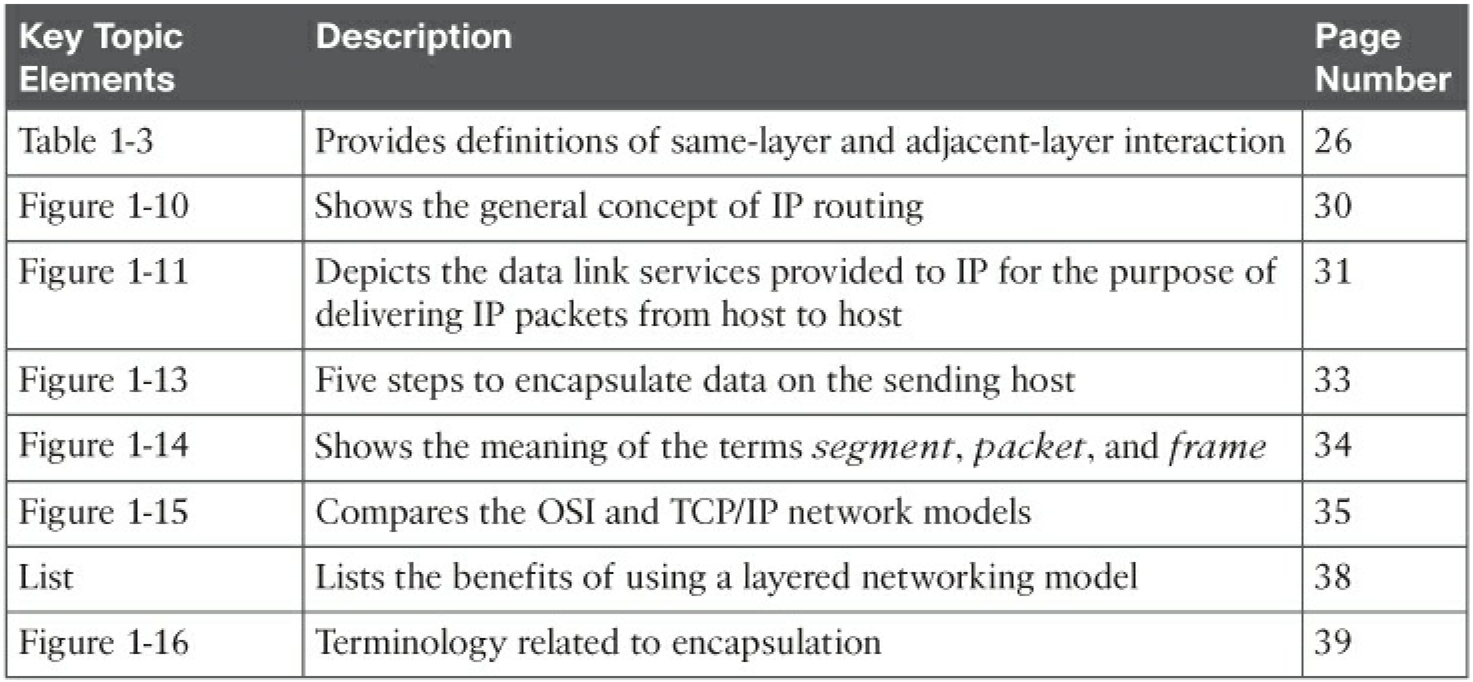
Figure 1-16. OSI Encapsulation and Protocol Data Units

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 1-6 lists these key topics and where each is discussed.

Table 1-6. Key Topics for Chapter 1



Key Topic Elements	Description	Page Number
Table 1-3	Provides definitions of same-layer and adjacent-layer interaction	26
Figure 1-10	Shows the general concept of IP routing	30
Figure 1-11	Depicts the data link services provided to IP for the purpose of delivering IP packets from host to host	31
Figure 1-13	Five steps to encapsulate data on the sending host	33
Figure 1-14	Shows the meaning of the terms *segment*, *packet*, and *frame*	34
Figure 1-15	Compares the OSI and TCP/IP network models	35
List	Lists the benefits of using a layered networking model	38
Figure 1-16	Terminology related to encapsulation	39

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

- adjacent-layer interaction
- deencapsulation
- encapsulation
- frame
- networking model
- packet
- protocol data unit (PDU)
- same-layer interaction
- segment

Chapter 2. Fundamentals of Ethernet LANs

This chapter covers the following exam topics:

Operation of IP Data Networks

Recognize the purpose and functions of various network devices such as Routers, Switches, Bridges and Hubs.

Select the components required to meet a given network specification.

Predict the data flow between two hosts across a network.

Identify the appropriate media, cables, ports, and connectors to connect Cisco network devices to other network devices and hosts in a LAN

LAN Switching Technologies

Determine the technology and media access control method for Ethernet networks

Most every enterprise computer network can be separated into two general types of technology: local-area networks (LAN) and wide-area networks (WAN). LANs typically connect nearby devices: devices in the same room, in the same building, or in a campus of buildings. In contrast, WANs connect devices that are typically relatively far apart. Together, LANs and WANs create a complete enterprise computer network, working together to do the job of a computer network: delivering data from one device to another.

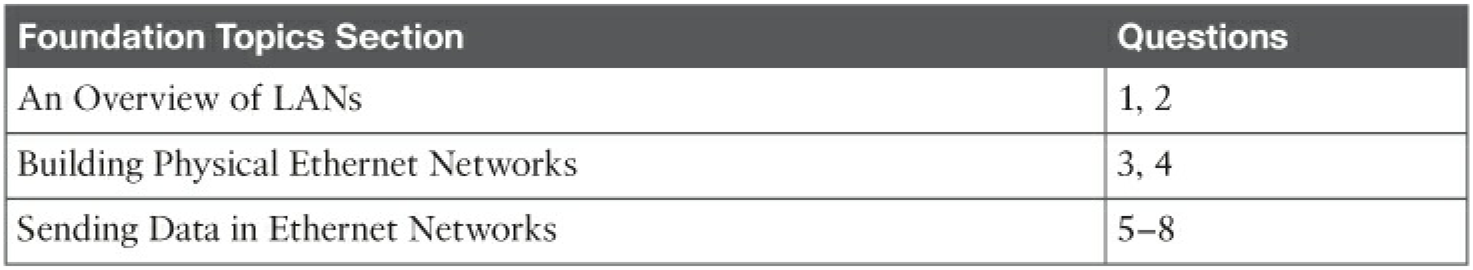
While many types of LANs have existed over the years, today’s networks use two general types of LANs: Ethernet LANs and wireless LANs. Ethernet LANs happen to use cables for the links between nodes, and because many types of cables use copper wires, Ethernet LANs are often called *wired LANs*. In comparison, wireless LANs do not use wires or cables, instead using radio waves for the links between nodes.

This chapter introduces Ethernet LANs, with more detailed coverage in Part II (Chapters 6 through 10).

“Do I Know This Already?” Quiz

Use the “Do I Know This Already?” quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the “Exam Preparation Tasks” section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, “Answers to the ‘Do I Know This Already?’ Quizzes.”

Table 2-1. “Do I Know This Already?” Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
An Overview of LANs	1, 2
Building Physical Ethernet Networks	3, 4
Sending Data in Ethernet Networks	5–8

1. In the LAN for a small office, some user devices connect to the LAN using a cable, while others connect using wireless technology (and no cable). Which of the following is true regarding the use of Ethernet in this LAN?

a. Only the devices that use cables are using Ethernet.

b. Only the devices that use wireless are using Ethernet.

c. Both the devices using cables and those using wireless are using Ethernet.

d. None of the devices are using Ethernet.

2. Which of the following Ethernet standards defines Gigabit Ethernet over UTP cabling?

a. 10GBASE-T

b. 100BASE-T

c. 1000BASE-T

d. None of the other answers is correct.

3. Which of the following is true about Ethernet crossover cables for Fast Ethernet?

a. Pins 1 and 2 are reversed on the other end of the cable.

b. Pins 1 and 2 on one end of the cable connect to pins 3 and 6 on the other end of the cable.

c. Pins 1 and 2 on one end of the cable connect to pins 3 and 4 on the other end of the cable.

d. The cable can be up to 1000 meters long to cross over between buildings.

e. None of the other answers is correct.

4. Each answer lists two types of devices used in a 100BASE-T network. If these devices were connected with UTP Ethernet cables, which pairs of devices would require a straight-through cable? (Choose three answers.)

a. PC and router

   b. PC and switch
   c. Hub and switch
   d. Router and hub
   e. Wireless access point (Ethernet port) and switch

5. Which of the following is true about the CSMA/CD algorithm?
   a. The algorithm never allows collisions to occur.
   b. Collisions can happen, but the algorithm defines how the computers should notice a collision and how to recover.
   c. The algorithm works with only two devices on the same Ethernet.
   d. None of the other answers is correct.

6. Which of the following is true about the Ethernet FCS field?
   a. Ethernet uses FCS for error recovery.
   b. It is 2 bytes long.
   c. It resides in the Ethernet trailer, not the Ethernet header.
   d. It is used for encryption.

7. Which of the following are true about the format of Ethernet addresses? (Choose three answers.)
   a. Each manufacturer puts a unique OUI code into the first 2 bytes of the address.
   b. Each manufacturer puts a unique OUI code into the first 3 bytes of the address.
   c. Each manufacturer puts a unique OUI code into the first half of the address.
   d. The part of the address that holds this manufacturer's code is called the MAC.
   e. The part of the address that holds this manufacturer's code is called the OUI.
   f. The part of the address that holds this manufacturer's code has no specific name.

8. Which of the following terms describe Ethernet addresses that can be used to send one frame that is delivered to multiple devices on the LAN? (Choose two answers.)
   a. Burned-in address
   b. Unicast address
   c. Broadcast address
   d. Multicast address

Answers to the "Do I Know This Already?" quiz:

1 A **2** C **3** B **4** B, D, and E **5** B **6** C **7** B, C, and E **8** C and D

Foundation Topics

An Overview of LANs

The term *Ethernet* refers to a family of LAN standards that together define the physical and data link layers of the world's most popular wired LAN technology. The standards, defined by the Institute of Electrical and Electronics Engineers (IEEE), defines the cabling, the connectors on the ends of the cables, the protocol rules, and everything else required to create an Ethernet LAN.

Typical SOHO LANs

To begin, first think about a Small Office / Home Office (SOHO) LAN today, specifically a LAN that uses only Ethernet LAN technology. First, the LAN needs a device called an Ethernet *LAN switch*, which provides many physical ports into which cables can be connected. An Ethernet uses *Ethernet cables*, which is a general reference to any cable that conforms to any of several Ethernet standards. The LAN uses Ethernet cables to connect different Ethernet devices or nodes to one of the switch's Ethernet ports.

Figure 2-1 shows a drawing of a SOHO Ethernet LAN. The figure shows a single LAN switch, five cables, and five other Ethernet nodes: three PCs, a printer, and one network device called a router. (The router connects the LAN to the WAN, in this case to the Internet.)

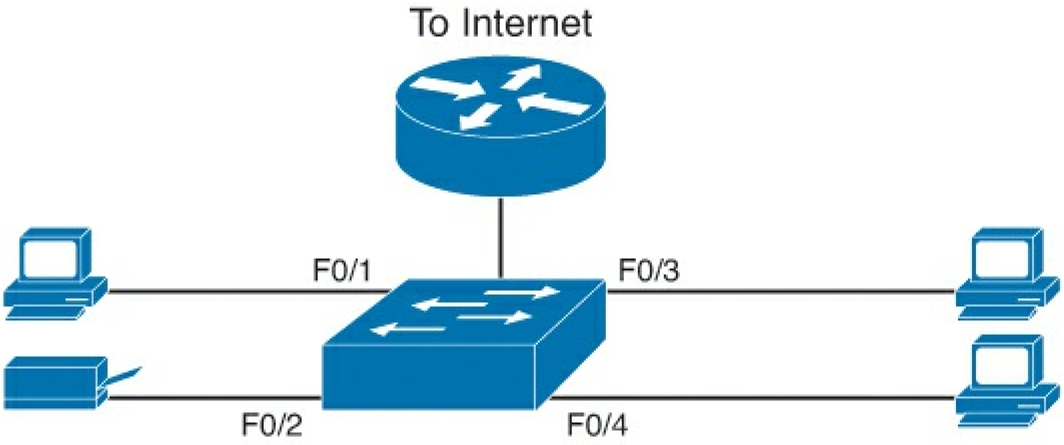


Figure 2-1. Typical Small Ethernet-Only SOHO LAN

Although Figure 2-1 shows a simple Ethernet LAN, many SOHO Ethernet LANs today combine the router and switch into a single device. Vendors sell consumer-grade integrated networking devices that work as a router and Ethernet switch, as well as doing other functions. These devices typically have "router" on the packaging, but many models also have four-port or eight-port Ethernet LAN switch ports built into the device.

Typical SOHO LANs today also support wireless LAN connections. Ethernet defines wired LAN technology only; in other words, Ethernet LANs use cables. However, you can build one LAN that uses both Ethernet LAN technology as well as wireless LAN technology, which is also defined by the IEEE. Wireless LANs, defined by the IEEE using standards that begin with 802.11, use radio waves to send the bits from one node to the next.

Most wireless LANs rely on yet another networking device: a wireless LAN *access point (AP)*. The AP acts somewhat like an Ethernet switch, in that all the wireless LAN nodes communicate with the Ethernet switch by sending and receiving data with the wireless AP. Of course, as a wireless device, the AP does not need Ethernet ports for cables, other than for a single Ethernet link to connect the AP to the Ethernet LAN, as shown in Figure 2-2.

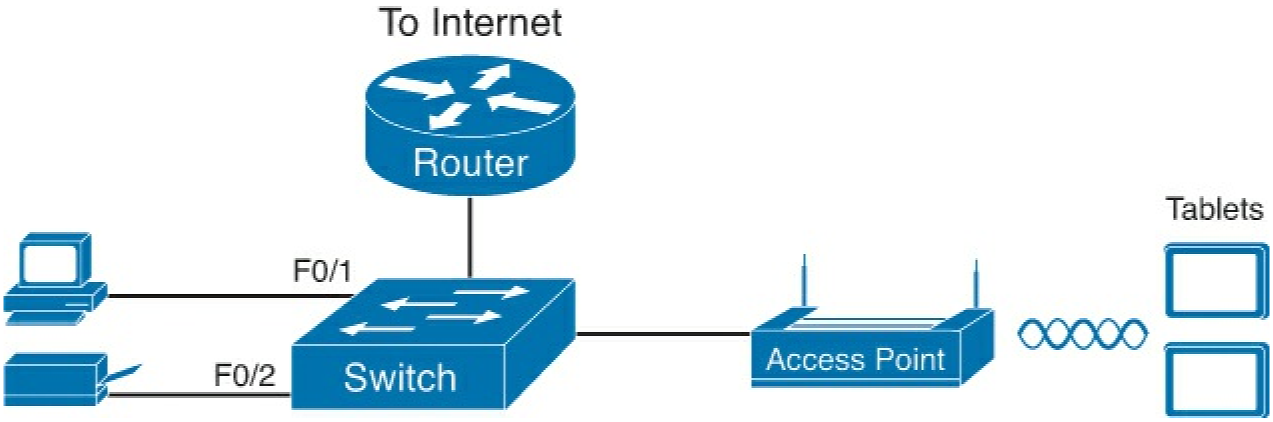


Figure 2-2. Typical Small Wired and Wireless SOHO LAN

Note that this drawing shows the router, Ethernet switch, and wireless LAN access point as three separate devices so that you can better understand the different roles. However, most SOHO networks today would use a single device, often labeled as a "wireless router" that does all these functions.

Typical Enterprise LANs

Enterprise networks have similar needs compared to a SOHO network, but on a much larger scale. For example, enterprise Ethernet LANs begin with LAN switches installed in a wiring closet behind a locked door on each floor of a building. The electricians install the Ethernet cabling from that wiring closet to cubicles and conference rooms where devices might need to connect to the LAN. At the same time, most enterprises also support wireless LANs in the same space, to allow people to roam around and still work and to support a growing number of devices that do not have an Ethernet LAN interface.

Figure 2-3 shows a conceptual view of a typical enterprise LAN in a three-story building. Each floor has an Ethernet LAN switch and a wireless LAN AP. To allow communication between floors, each per-floor switch connects to one centralized distribution switch. For example, PC3 can send data to PC2, but it would first flow through switch SW3 to the first floor to the distribution switch (SWD) and then back up through switch SW2 on the second floor.

Key Topic

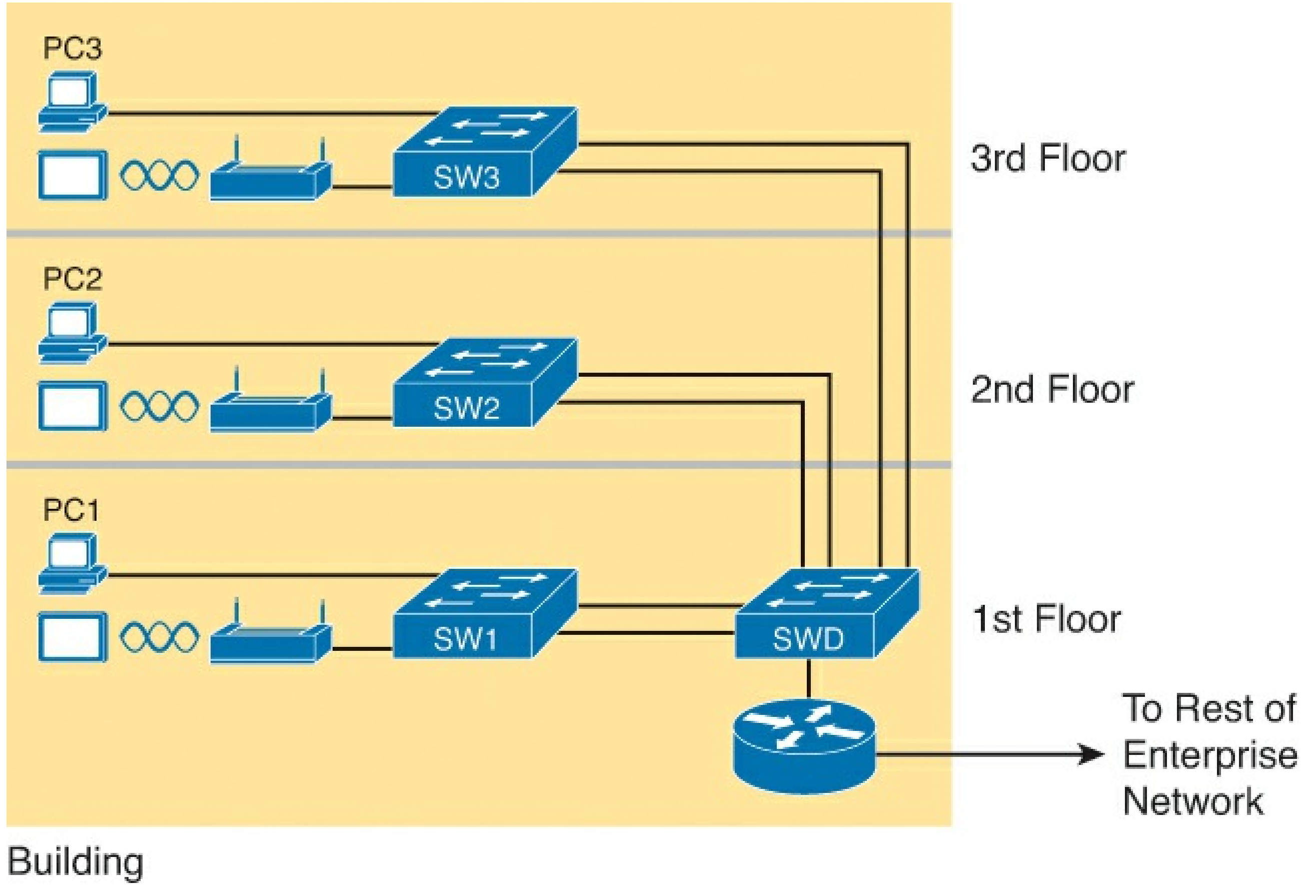


Figure 2-3. Single-Building Enterprise Wired and Wireless LAN

The figure also shows the typical way to connect a LAN to a WAN using a router. LAN switches and wireless access points work to create the LAN itself. Routers connect to both the LAN and the WAN. To connect to the LAN, the router simply uses an Ethernet LAN interface and an Ethernet cable, as shown on the lower right of Figure 2-3.

The rest of this chapter focuses on Ethernet in particular.

The Variety of Ethernet Physical Layer Standards

The term *Ethernet* refers to an entire family of standards. Some standards define the specifics of how to send data over a particular type of cabling, and at a particular speed. Other standards define protocols, or rules, that the Ethernet nodes must follow to be a part of an Ethernet LAN. All these Ethernet standards come from the IEEE and include the number 802.3 as the beginning part of the standard name.

Ethernet supports a large variety of options for physical Ethernet links given its long history over the last 40 or so years. Today, Ethernet includes many standards for different kinds of optical and copper cabling, and for speeds from 10 megabits per second (Mbps) up to 100 gigabits per second (100 Gbps). The standards also differ as far as the types of cabling and the allowed length of the cabling.

The most fundamental cabling choice has to do with the materials used inside the cable for the physical transmission of bits: either copper wires or glass fibers. The use of *unshielded twisted-pair (UTP)* cabling saves money compared to optical fibers, with Ethernet nodes using the wires inside the cable to send data over electrical circuits. Fiber-optic cabling, the more expensive alternative, allows Ethernet nodes to send light over glass fibers in the center of the cable. Although more expensive, optical cables typically allow longer cabling distances between nodes.

To be ready to choose the products to purchase for a new Ethernet LAN, a network engineer must know the names and features of the different Ethernet standards supported in Ethernet products. The IEEE defines Ethernet physical layer standards using a couple of naming conventions. The formal name begins with "802.3" followed by some suffix letters. The IEEE also uses more meaningful shortcut names that identify the speed, as well as a clue about whether the cabling is UTP (with a suffix that includes "T") or fiber (with a suffix that includes "X").

Table 2-2 lists a few Ethernet physical layer standards. First, the table lists enough names so that you get a sense of the IEEE naming conventions. It also lists the four most common standards that use UTP cabling, because this book's discussion of Ethernet focuses mainly on the UTP options.

Key Topic

Table 2-2. Examples of Types of Ethernet

Speed	Common Name	Informal IEEE Standard Name	Formal IEEE Standard Name	Cable Type, Maximum Length
10 Mbps	Ethernet	10BASE-T	802.3	Copper, 100 m
100 Mbps	Fast Ethernet	100BASE-T	802.3u	Copper, 100 m
1000 Mbps	Gigabit Ethernet	1000BASE-LX	802.3z	Fiber, 5000 m
1000 Mbps	Gigabit Ethernet	1000BASE-T	802.3ab	Copper, 100 m
10 Gbps	10 Gig Ethernet	10GBASE-T	802.3an	Copper, 100 m

Note

Fiber-optic cabling contains long thin strands of fiberglass. The attached Ethernet nodes send light over the glass fiber in the cable, encoding the bits as changes in the light.

Consistent Behavior over All Links Using the Ethernet Data Link Layer

Although Ethernet includes many physical layer standards, Ethernet acts like a single LAN technology because it uses the same data link layer standard over all types of Ethernet physical links. That standard defines a common Ethernet header and trailer. (As a reminder, the header and trailer are bytes of overhead data that Ethernet uses to do its job of sending data over a LAN.) No matter whether the data flows over a UTP cable, or any kind of fiber cable, and no matter the speed, the data link header and trailer use the same format.

While the physical layer standards focus on sending bits over a cable, the Ethernet data link protocols focus on sending an *Ethernet frame* from source to destination Ethernet node. From a data link perspective, nodes build and forward frames. As first defined in Chapter 1, "The TCP/IP and OSI Networking Models," the term *frame* specifically refers to the header and trailer of a data link protocol, plus the data encapsulated inside that header and trailer. The various Ethernet nodes simply forward the frame, over all the required links, to deliver the frame to the correct destination.

Figure 2-4 shows an example of the process. In this case, PC1 sends an Ethernet frame to PC3. The frame travels over a UTP link to Ethernet switch SW1, then over fiber links to Ethernet switches SW2 and SW3, and finally over another UTP link to PC3. Note that the bits actually travel at four different speeds in this example: 10 Mbps, 1 Gbps, 10 Gbps, and 100 Mbps, respectively.

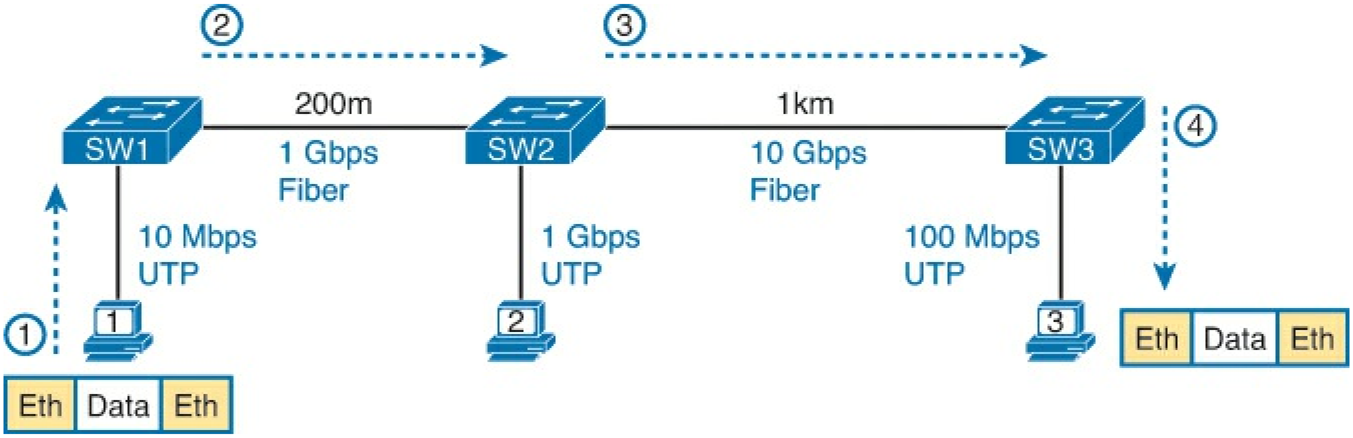


Figure 2-4. Ethernet LAN Forwards a Data Link Frame over Many Types of Links

So, what is an Ethernet LAN? It is a combination of user devices, LAN switches, and different kinds of cabling. Each link can use different types of cables, at different speeds. However, they all work together to deliver Ethernet frames from the one device on the LAN to some other device.

The rest of this chapter takes these concepts a little deeper, first looking at the details of building the physical Ethernet network, followed by some discussion of the rules for forwarding frames through an Ethernet LAN. *Ethernet frame* from source to destination Ethernet node.

Building Physical Ethernet Networks with UTP

For this second of three major sections of this chapter, I focus on the individual physical links between any two Ethernet nodes. Before the Ethernet network as a whole can send Ethernet frames between user devices, each node must be ready and able to send data over an individual physical link. This section looks at some of the particulars of how Ethernet sends data over these links.

This section focuses on the three most commonly used Ethernet standards: 10BASE-T (Ethernet), 100BASE-T (Fast Ethernet, or FE), and 1000BASE-T (Gigabit Ethernet, or GE). Specifically, this section looks at the details of sending data in both directions over a UTP cable. It then examines the specific wiring of the UTP cables used for 10-Mbps, 100-Mbps, and 1000-Mbps Ethernet.

Transmitting Data Using Twisted Pairs

While it is true that Ethernet sends data over UTP cables, the physical means to send the data uses electricity that flows over the wires inside the UTP cable. To better understand how Ethernet sends data using electricity, break the idea down into two parts: how to create an electrical circuit and then how to make that electrical signal communicate 1s and 0s.

First, to create one electrical circuit, Ethernet defines how to use the two wires inside a single twisted pair of wires, as shown Figure 2-5. The figure does not show a UTP cable between two nodes, but instead shows two individual wires that are inside the UTP cable. An electrical circuit requires a complete loop, so the two nodes, using circuitry on their Ethernet ports, connect the wires in one pair to complete a loop, allowing electricity to flow.

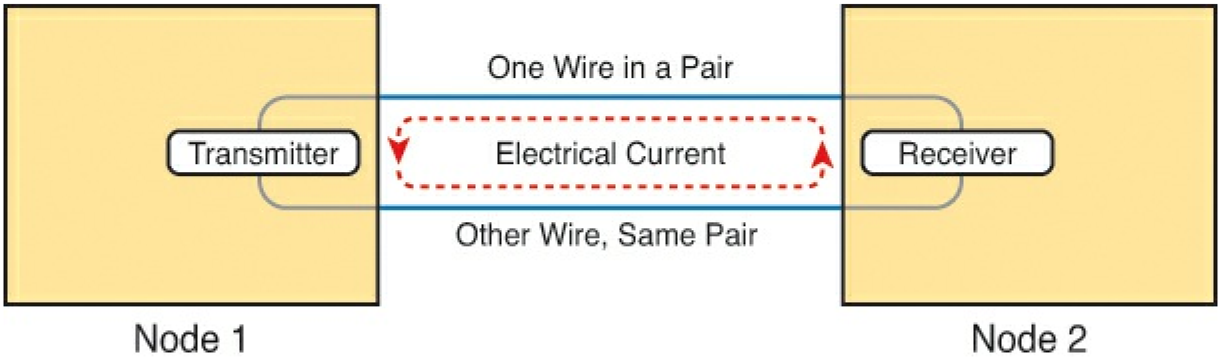


Figure 2-5. Creating One Electrical Circuit over One Pair to Send in One Direction

To send data, the two devices follow some rules called an *encoding scheme*. The idea works a lot like when two people talk, using the same language: The speaker says some words in a particular language, and the listener, because she speaks the same language, can understand the spoken words. With an encoding scheme, the transmitting node changes the electrical signal over time, while the other node, the receiver, using the same rules, interprets those changes as either 0s or 1s. (For example, 10BASE-T uses an encoding scheme that encodes a binary 0 as a transition from higher voltage to lower voltage during the middle of a 1/10,000,000th-of-a-second interval.)

Note that in an actual UTP cable, the wires will be twisted together and not parallel, as shown in Figure 2-5. The twisting helps solve some important physical transmission issues. When electrical current passes over any wire, it creates *electromagnetic interference (EMI)* that interferes with the electrical signals in nearby wires, including the wires in the same cable. (EMI between wire pairs in the same cable is called *crosstalk*.) Twisting the wire pairs together helps cancel out most of the EMI, so most networking physical links that use copper wires used twisted pairs.

Breaking Down a UTP Ethernet Link

The term *Ethernet link* refers to any physical cable between two Ethernet nodes. To learn about how a UTP Ethernet link works, it helps to break down the physical link into those basic pieces, as shown in Figure 2-6: the cable itself, the connectors on the ends of the cable, and the matching ports on the devices into which the connectors will be inserted.

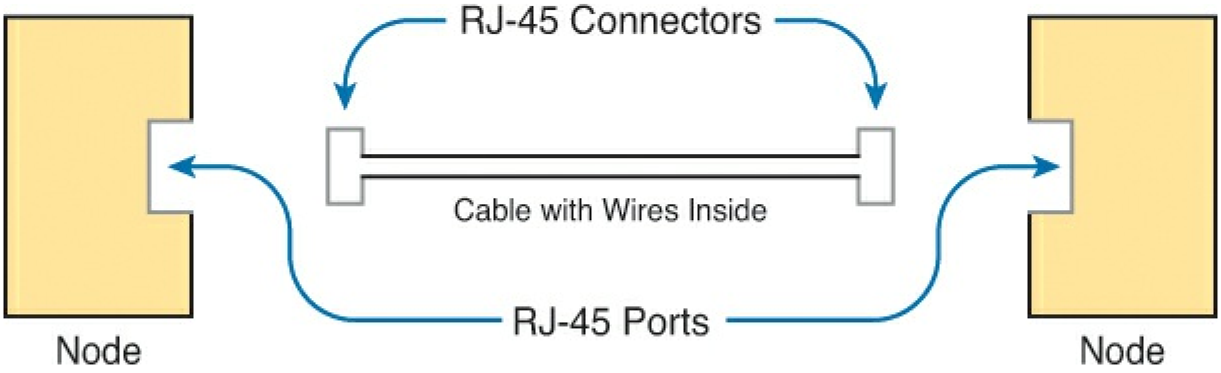


Figure 2-6. Basic Components of an Ethernet Link

First, think about the UTP cable itself. The cable holds some copper wires, grouped as twisted pairs. The 10BASE-T and 100BASE-T standards require two pairs of wires, while the 1000BASE-T standard requires four pairs. Each wire has a color-coded plastic coating, with the wires in a pair having a color scheme. For example, for the blue wire pair, one wire's coating is all blue, while the other wire's coating is blue-and-white striped.

Many Ethernet UTP cables use an RJ-45 connector on both ends. The RJ-45 connector has eight physical locations into which the eight wires in the cable can be inserted, called *pin positions*, or simply *pins*. These pins create a place where the ends of the copper wires can touch the electronics inside the nodes at the end of the physical link so that electricity can flow.

Note

If available, find a nearby Ethernet UTP cable and examine the connectors closely. Look for the pin positions and the colors of the wires in the connector.

To complete the physical link, the nodes each need an RJ-45 *Ethernet port* that matches the RJ-45 connectors on the cable so that the connectors on the ends of the cable can connect to each node. PCs often include this RJ-45 Ethernet port as part of a *network interface card (NIC)*, which can be an expansion card on the PC or can be built into the system itself. Switches typically have many RJ-45 ports because switches give user devices a place to connect to the Ethernet LAN.

Figure 2-7 shows photos of the cables, connectors, and ports.

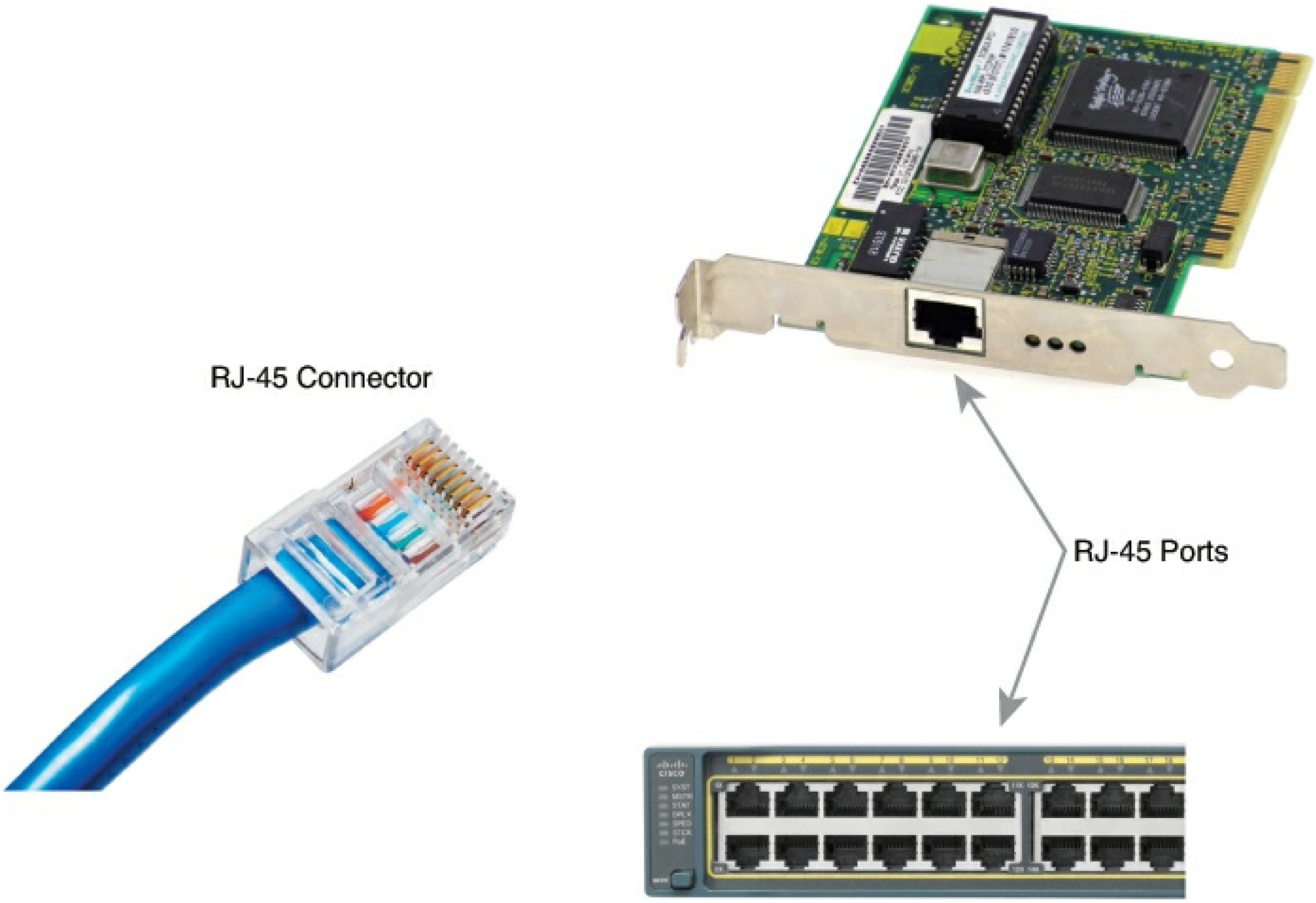


Figure 2-7. RJ-45 Connectors and Ports (Ethernet NIC © Mark Jansen, LAN Cable © Mikko Pitkänen)

Note

The RJ-45 connector is slightly wider, but otherwise similar, to the RJ-11 connectors commonly used for telephone cables in homes in North America.

The figure shows a connector on the left and ports on the right. The left shows the eight pin positions in the end of the RJ-45 connector. The upper right shows an Ethernet NIC that is not yet installed in a computer. The lower-right part of the figure shows the side of a Cisco 2960 switch, with multiple RJ-45 ports, allowing multiple devices to easily connect to the Ethernet network.

Finally, while RJ-45 connectors with UTP cabling can be common, Cisco LAN switches often support other types of connectors as well. When you buy one of the many models of Cisco switches, you need to think about the mix and numbers of each type of physical ports you want on the switch.

To give its customers flexibility as to the type of Ethernet links, even after the customer has bought the switch, Cisco switches include some physical ports whose port hardware can be changed later, after you purchase the switch. One type of port is called a *gigabit interface converter (GBIC)*, which happened to first arrive on the market around the same time as Gigabit Ethernet, so it was given the same “gigabit” name. More recently, improved smaller types of removable interfaces, called *small form-factor pluggables (SFP)*, provide the same function of giving users the ability to swap hardware and change the type of physical link. Figure 2-8 shows a photo of a Cisco switch, with an SFP sitting slightly outside the SFP slot.

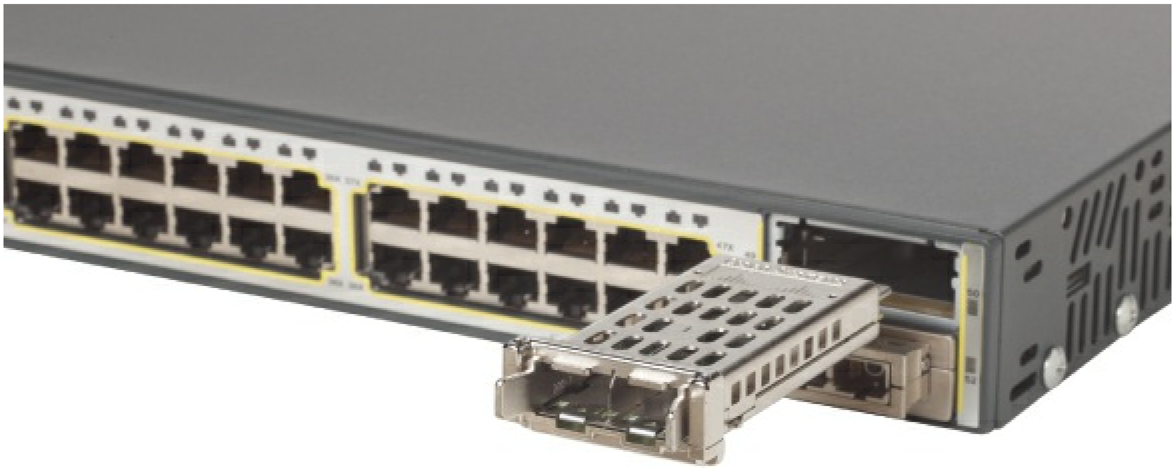


Figure 2-8. Gigabit Fiber SFP Sitting Just Outside a Switch SFP Port

UTP Cabling Pinouts for 10BASE-T and 100BASE-T

So far in this section, you have learned about the equivalent of how to drive a truck on a 1000-acre ranch, but you do not know the equivalent of the local traffic rules. If you worked the ranch, you could drive the truck all over the ranch, any place you wanted to go, and the police would not mind. However, as soon as you get on the public roads, the police want you to behave and follow the rules. Similarly, so far this chapter has discussed the general principles of how to send data, but it has not yet detailed some important rules for Ethernet cabling: the rules of the road so that all the devices send data using the right wires inside the cable.

This next topic discusses conventions for 10BASE-T and 100BASE-T together, because they use UTP cabling in similar ways (including the use of only two wire pairs). A short comparison of the wiring for 1000BASE-T (Gigabit Ethernet), which uses four pairs, follows.

Straight-Through Cable Pinout

10BASE-T and 100BASE-T use two pair of wires in a UTP cable, one for each direction, as shown in Figure 2-9. The figure shows four wires, all of which sit inside a single UTP cable that connects a PC and a LAN switch. In this example, the PC on the left transmits using the top pair, and the switch on the right transmits using the bottom pair.

Key Topic

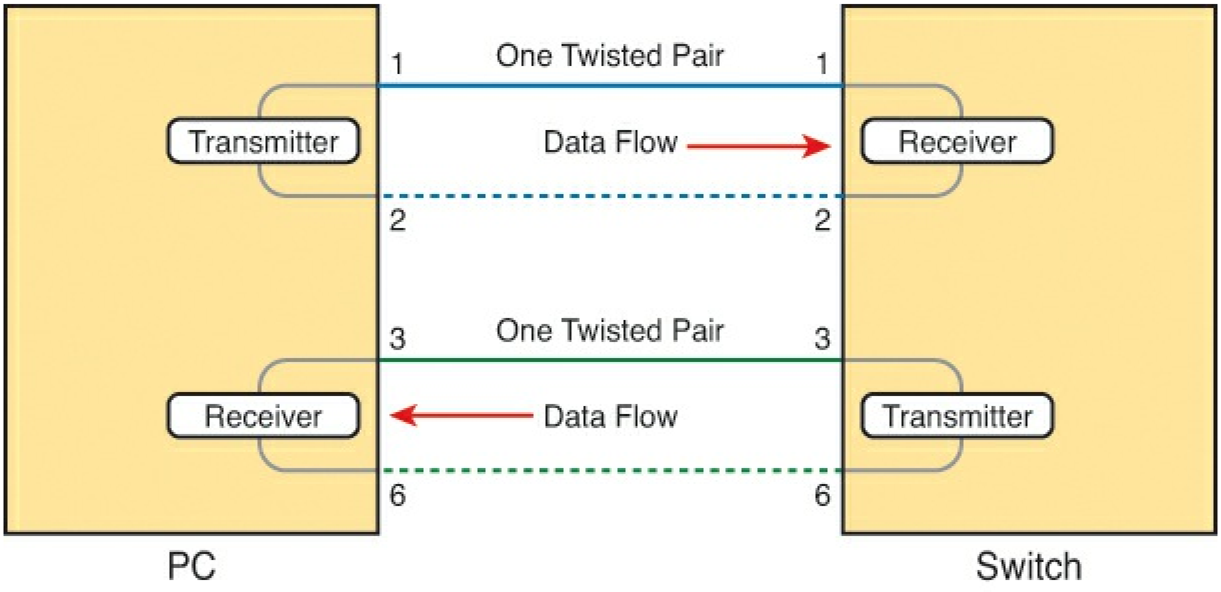


Figure 2-9. Using One Pair for Each Transmission Direction with 10-and 100-Mbps Ethernet

For correct transmission over the link, the wires in the UTP cable must be connected to the correct pin positions in the RJ-45 connectors. For example, in Figure 2-9, the transmitter on the PC on the left must know the pin positions of the two wires it should use to transmit. Those two wires must be connected to the correct pins in the RJ-45 connector on the switch, so that the switch's receiver logic can use the correct wires.

To understand the wiring of the cable—which wires need to be in which pin positions on both ends of the cable—you need to first understand how the NICs and switches work. As a rule, Ethernet NIC transmitters use the pair connected to pins 1 and 2;

the NIC receivers use a pair of wires at pin positions 3 and 6. LAN switches, knowing those facts about what Ethernet NICs do, do the opposite: Their receivers use the wire pair at pins 1 and 2, and their transmitters use the wire pair at pins 3 and 6.

To allow a PC NIC to communicate with a switch, the UTP cable must also use a *straight-through cable pinout*. The term *pinout* refers to the wiring of which color wire is placed in each of the eight numbered pin positions in the RJ-45 connector. An Ethernet straight-through cable connects the wire at pin 1 on one end of the cable to pin 1 at the other end of the cable; the wire at pin 2 needs to connect to pin 2 on the other end of the cable; pin 3 on one end connects to pin 3 on the other, and so on. Also, it uses the wires in one wire pair at pins 1 and 2, and another pair at pins 3 and 6.

Key Topic

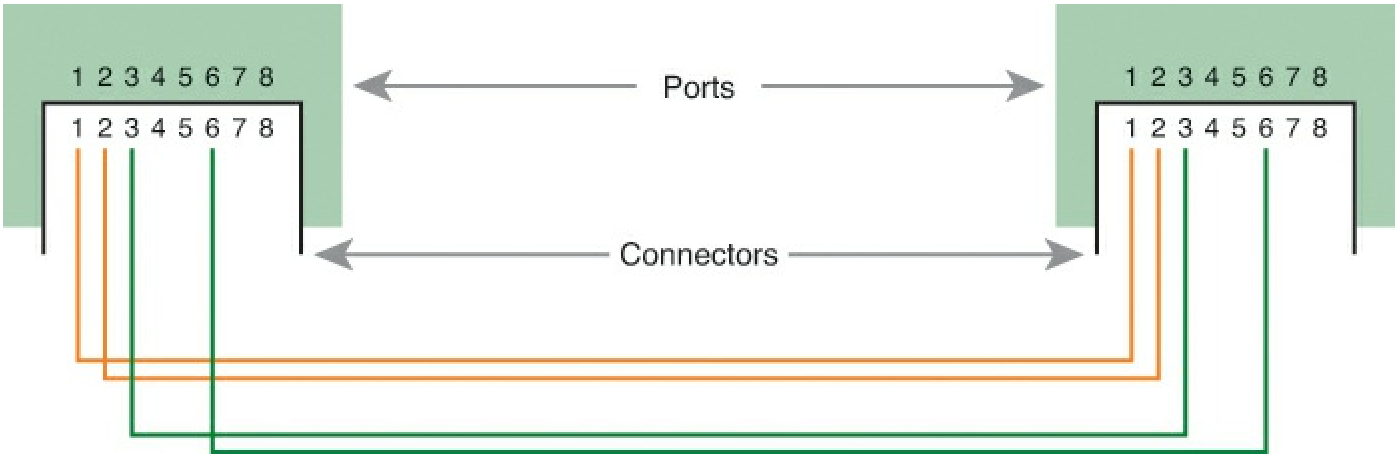


Figure 2-10. 10BASE-T and 100BASE-T Straight-Through Cable Pinout

Figure 2-11 shows one final perspective on the straight-through cable pinout. In this case, PC Larry connects to a LAN switch. Note that the figure again does not show the UTP cable, but instead shows the wires that sit inside the cable, to emphasize the idea of wire pairs and pins.

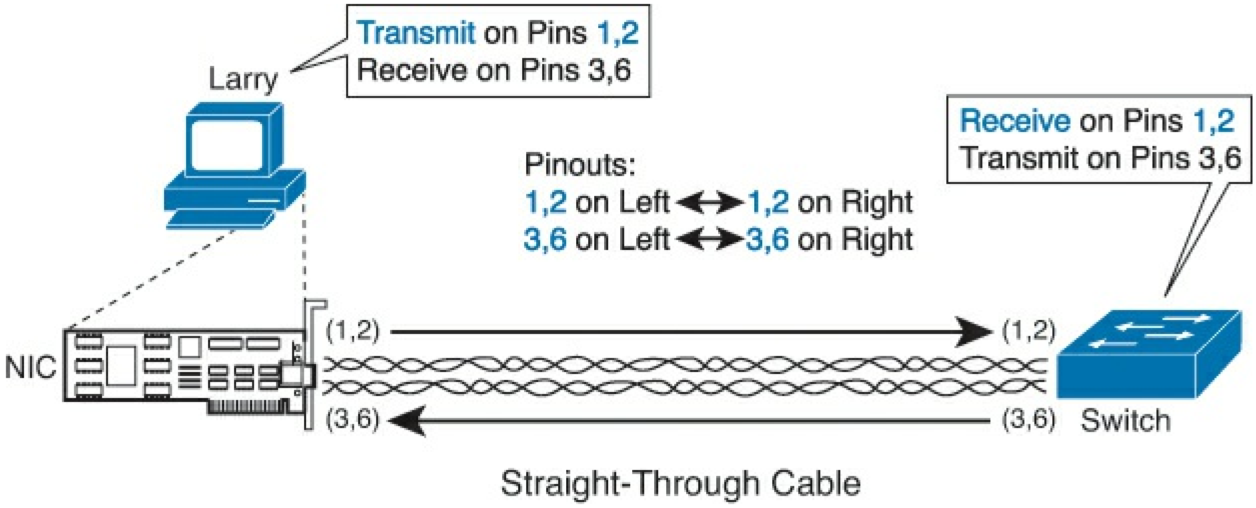


Figure 2-11. Ethernet Straight-Through Cable Concept

Crossover Cable Pinout

A straight-through cable works correctly when the nodes use opposite pairs for transmitting data. However, when two like devices connect to an Ethernet link, they both transmit on over the same pins. In that case, you then need another type of cabling pinout called a *crossover cable*. The crossover cable pinout crosses the pair at the transmit pins on each device to the receive pins on the opposite device.

While that previous sentence is true, this concept is much clearer with a figure such as Figure 2-12. The figure shows what happens on a link between two switches. The two switches both transmit on the pair at pins 3 and 6, and they both receive on the pair at pins 1 and 2. So, the cable must connect a pair at pins 3 and 6 on each side to pins 1 and 2 on the other side, connecting to the other node's receiver logic. The top of the figure shows the literal pinouts, and the bottom half shows a conceptual diagram.

Key Topic

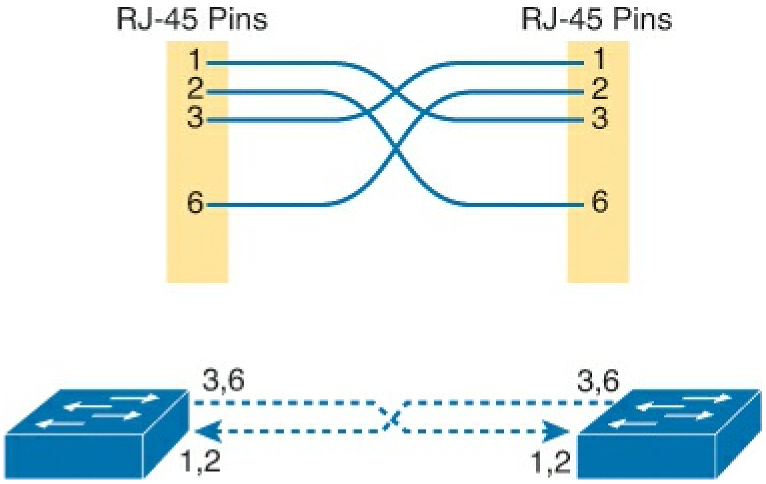

RJ-45 Pins
RJ-45 Pins
1
2
3
6
1
2
3
6
3,6
3,6
1,2
1,2

Figure 2-12. Crossover Ethernet Cable

Choosing the Right Cable Pinouts

For the exam, you should be well prepared to choose which type of cable (straight-through or crossover) is needed in each part of the network. The key is to know whether a device acts like a PC NIC, transmitting at pins 1 and 2, or like a switch, transmitting at pins 3 and 6. Then, just apply the following logic:

> **Crossover cable:** If the endpoints transmit on the same pin pair
>
> **Straight-through cable:** If the endpoints transmit on different pin pairs

Table 2-3 lists the devices mentioned in this book and the pin pairs they use, assuming that they use 10BASE-T and 100BASE-TX.

Key Topic

Table 2-3. 10BASE-T and 100BASE-TX Pin Pairs Used

Transmits on Pins 1,2	Transmits on Pins 3,6
PC NICs	Hubs
Routers	Switches
Wireless access point (Ethernet interface)	—

For example, Figure 2-13 shows a campus LAN in a single building. In this case, several straight-through cables are used to connect PCs to switches. Additionally, the cables connecting the switches require crossover cables.

Key Topic

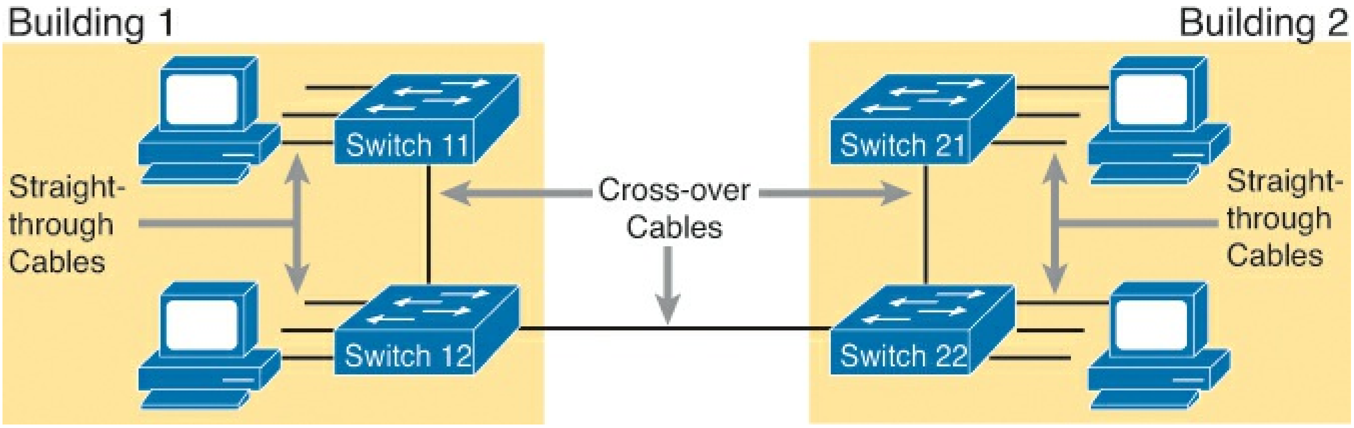

Building 1
Building 2
Switch 11
Switch 21
Straight-through Cables
Cross-over Cables
Straight-through Cables
Switch 12
Switch 22

Figure 2-13. Typical Uses for Straight-Through and Crossover Ethernet Cables

Note

If you have some experience with installing LANs, you might be thinking that you have used the wrong cable before (straight-through or crossover), but the cable worked. Cisco switches have a feature called *auto-mdix* that notices when the wrong cable is used and automatically changes its logic to make the link work. However, for the exams, be ready to identify whether the correct cable is shown in the figures.

UTP Cabling Pinouts for 1000BASE-T

1000BASE-T (Gigabit Ethernet) differs from 10BASE-T and 100BASE-T as far as the cabling and pinouts. First, 1000BASE-T requires four wire pairs. Second, it uses more advanced electronics that allow both ends to transmit and receive simultaneously on each wire pair. However, the wiring pinouts for 1000BASE-T work almost identically to the earlier standards, adding details for the additional two pairs.

The straight-through cable connects each pin with the same numbered pin on the other side, but it does so for all eight pins—pin 1 to pin 1, pin 2 to pin 2, up through pin 8. It keeps one pair at pins 1 and 2 and another at pins 3 and 6, just like in the earlier wiring. It adds a pair at pins 4 and 5 and the final pair at pins 7 and 8 (refer to Figure 2-12).

The Gigabit Ethernet crossover cable crosses the same two-wire pairs as the crossover cable for the other types of Ethernet (the pairs at pins 1,2 and 3,6). It also crosses the two new pairs as well (the pair at pins 4,5 with the pair at pins 7,8).

Sending Data in Ethernet Networks

Although physical layer standards vary quite a bit, other parts of the Ethernet standards work the same way, regardless of the type of physical Ethernet link. Next, this final major section of this chapter looks at several protocols and rules that Ethernet uses regardless of the type of link. In particular, this section examines the details of the Ethernet data link layer protocol, plus how Ethernet nodes, switches, and hubs forward Ethernet frames through an Ethernet LAN.

Ethernet Data Link Protocols

One of the most significant strengths of the Ethernet family of protocols is that these protocols use the same data link standard. In fact, the core parts of the data link standard date back to the original Ethernet standards.

The Ethernet data link protocol defines the Ethernet frame: an Ethernet header at the front, the encapsulated data in the middle, and an Ethernet trailer at the end. Ethernet actually defines a few alternate formats for the header, with the frame format shown in Figure 2-14 being commonly used today.

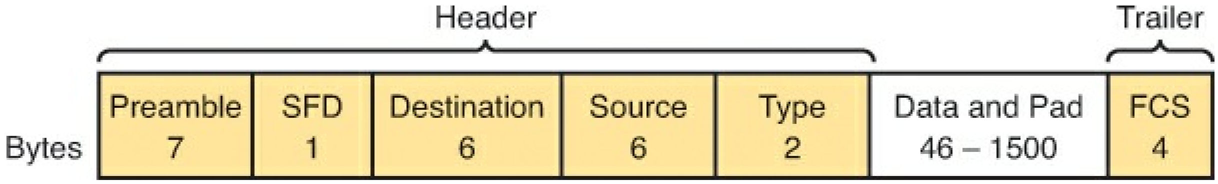
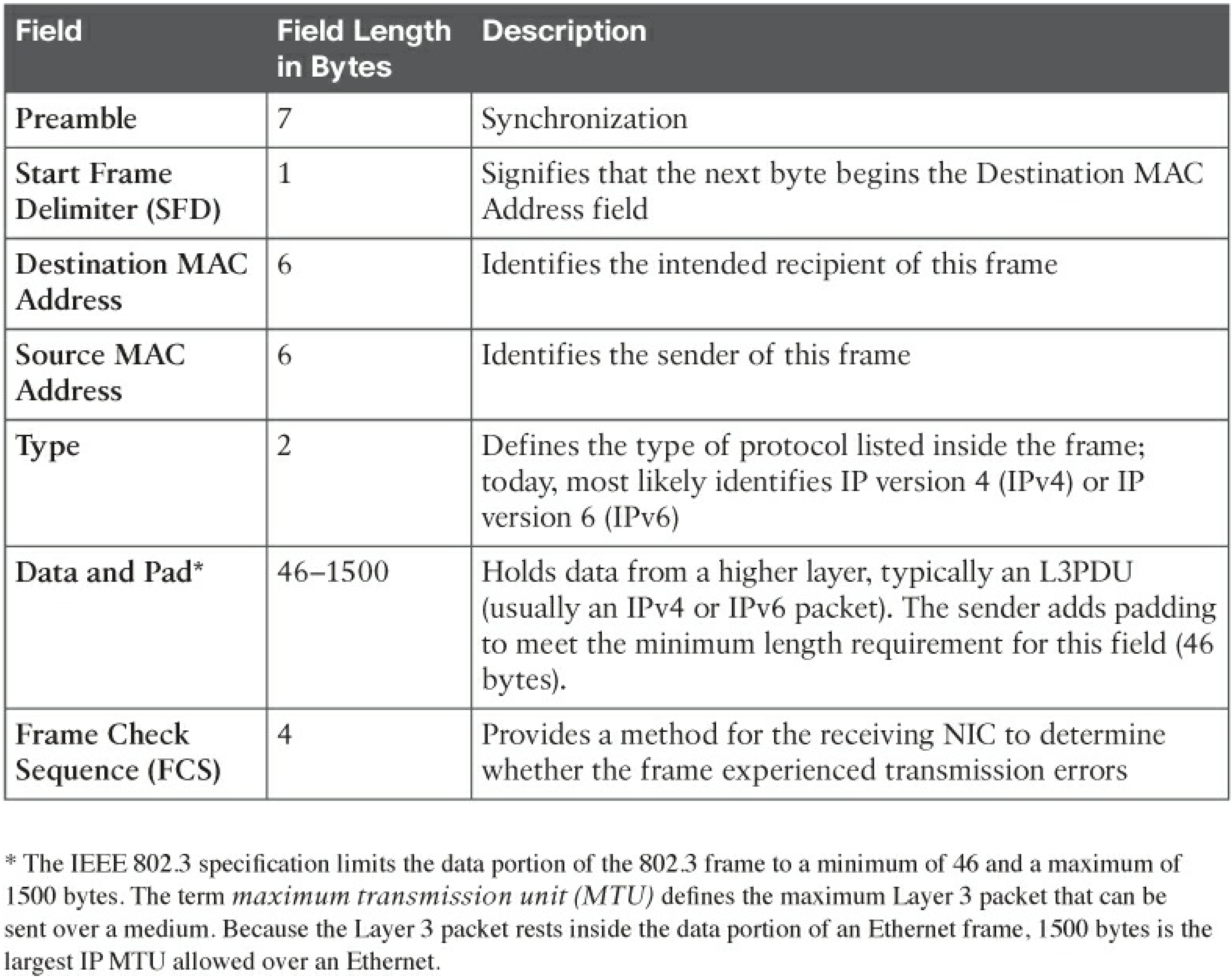


Figure 2-14. Commonly Used Ethernet Frame Format

While all the fields in the frame matter, some matter more to the topics discussed in this book. Table 2-4 lists the fields in the header and trailer, and a brief description for reference, with the upcoming pages including more detail about a few of these fields.

Table 2-4. IEEE 802.3 Ethernet Header and Trailer Fields



Field	Field Length in Bytes	Description
Preamble	7	Synchronization
Start Frame Delimiter (SFD)	1	Signifies that the next byte begins the Destination MAC Address field
Destination MAC Address	6	Identifies the intended recipient of this frame
Source MAC Address	6	Identifies the sender of this frame
Type	2	Defines the type of protocol listed inside the frame; today, most likely identifies IP version 4 (IPv4) or IP version 6 (IPv6)
Data and Pad*	46–1500	Holds data from a higher layer, typically an L3PDU (usually an IPv4 or IPv6 packet). The sender adds padding to meet the minimum length requirement for this field (46 bytes).
Frame Check Sequence (FCS)	4	Provides a method for the receiving NIC to determine whether the frame experienced transmission errors

* The IEEE 802.3 specification limits the data portion of the 802.3 frame to a minimum of 46 and a maximum of 1500 bytes. The term *maximum transmission unit (MTU)* defines the maximum Layer 3 packet that can be sent over a medium. Because the Layer 3 packet rests inside the data portion of an Ethernet frame, 1500 bytes is the largest IP MTU allowed over an Ethernet.

Ethernet Addressing

The source and destination Ethernet address fields play a big role in much of the Ethernet logic included in the CCENT and CCNA certifications. The general idea for each is relatively simple: The sending node puts its own address in the source address field and the intended Ethernet destination device's address in the destination address field. The sender transmits the frame, expecting that the Ethernet LAN, as a whole, will deliver the frame to that correct destination.

Ethernet addresses, also called *Media Access Control (MAC)* addresses, are 6-byte-long (48-bit-long) binary numbers. For convenience, most computers list MAC addresses as 12-digit hexadecimal numbers. Cisco devices typically add some periods to the number for easier readability as well; for example, a Cisco switch might list a MAC address as 0000.0C12.3456.

Most MAC addresses represent a single NIC or other Ethernet port, so these addresses are often called a *unicast* Ethernet address. The term *unicast* is simply a formal way to refer to the fact that the address represents one interface to the Ethernet LAN. (This term also contrasts with two other types of Ethernet addresses, *broadcast* and *multicast*, which will be defined later in this section.)

The entire idea of sending data to a destination unicast MAC address works well, but it only works if all the unicast MAC addresses are unique. If two NICs tried to use the same MAC address, there could be confusion. (The problem would be like the confusion caused to the postal service, if you and I both tried to use the same mailing address—would the postal service deliver mail to your house or mine?). If two PCs on the same Ethernet tried to use the same MAC address, to which PC should frames sent to that MAC address be delivered?

Ethernet solves this problem using an administrative process so that, at the time of manufacture, all Ethernet devices are assigned a universally unique MAC address. Before a manufacturer can build Ethernet products, it must ask the IEEE to assign the manufacturer a universally unique 3-byte code, called the *organizationally unique identifier (OUI)*. The manufacturer agrees to give all NICs (and other Ethernet products) a MAC address that begins with its assigned 3-byte OUI. The manufacturer also assigns a unique value for the last 3 bytes, a number that manufacturer has never used with that OUI. As a result, the MAC address of every device in the universe is unique.

Note

The IEEE also calls these universal MAC addresses global MAC addresses.

Figure 2-15 shows the structure of the unicast MAC address, with the OUI.

Key Topic

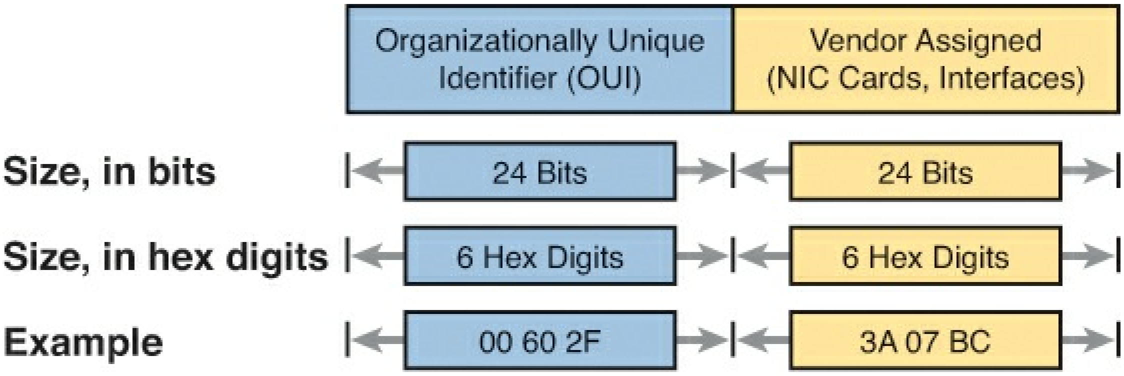


Figure 2-15. Structure of Unicast Ethernet Addresses

Ethernet addresses go by many names: LAN address, Ethernet address, hardware address, burned-in address, physical address, universal address, or MAC address. For example, the term *burned-in address (BIA)* refers to the idea that a permanent MAC address has been encoded (burned into) the ROM chip on the NIC. As another example, the IEEE uses the term *universal address* to emphasize the fact that the address assigned to a NIC by a manufacturer should be unique among all MAC addresses in the universe.

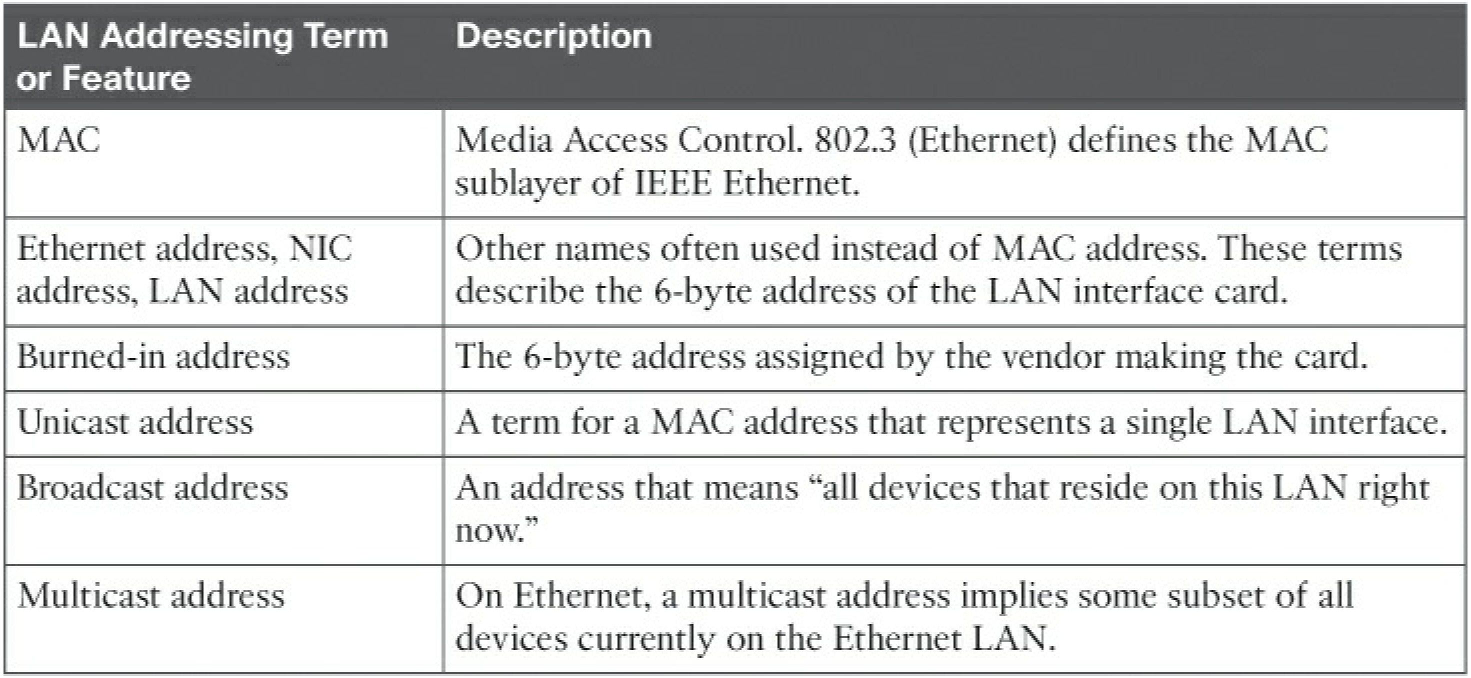
In addition to unicast addresses, Ethernet also uses group addresses. *Group addresses* identify more than one LAN interface card. A frame sent to a group address might be delivered to a small set of devices on the LAN, or even to all devices on the LAN. In fact, the IEEE defines two general categories of group addresses for Ethernet:

Broadcast address: Frames sent to this address should be delivered to all devices on the Ethernet LAN. It has a value of FFFF.FFFF.FFFF.

Multicast addresses: Frames sent to a multicast Ethernet address will be copied and forwarded to a subset of the devices on the LAN that volunteers to receive frames sent to a specific multicast address.

Table 2-5 summarizes most of the details about MAC addresses.

Table 2-5. LAN MAC Address Terminology and Features



LAN Addressing Term or Feature	Description
MAC	Media Access Control. 802.3 (Ethernet) defines the MAC sublayer of IEEE Ethernet.
Ethernet address, NIC address, LAN address	Other names often used instead of MAC address. These terms describe the 6-byte address of the LAN interface card.
Burned-in address	The 6-byte address assigned by the vendor making the card.
Unicast address	A term for a MAC address that represents a single LAN interface.
Broadcast address	An address that means "all devices that reside on this LAN right now."
Multicast address	On Ethernet, a multicast address implies some subset of all devices currently on the Ethernet LAN.

Identifying Network Layer Protocols with the Ethernet Type Field

While the Ethernet header's address fields play an important and more obvious role in Ethernet LANs, the Ethernet Type field plays a much less obvious role. The Ethernet Type field, or EtherType, sits in the Ethernet data link layer header, but its purpose is to directly help the network processing on routers and hosts. Basically, the Type field identifies the type of network layer (Layer 3) packet that sits inside the Ethernet frame.

First, think about what sits inside the data part of the Ethernet frame shown earlier in Figure 2-14. Typically, it holds the network layer packet created by the network layer protocol on some device in the network. Over the years, those protocols have included IBM Systems Network Architecture (SNA), Novell NetWare, Digital Equipment Corporation's DECnet, and Apple Computer's AppleTalk. Today, the most common network layer protocols are both from TCP/IP: IP version 4 (IPv4) and IP version 6 (IPv6).

The original host has a place to insert a value (a hexadecimal number) to identify the type of packet encapsulated inside the Ethernet frame. However, what number should the sender put in the header to identify an IPv4 packet as the type? Or an IPv6 packet? As it turns out, the IEEE manages a list of EtherType values, so that every network layer protocol that needs a unique EtherType value can have a number. The sender just has to know the list. (Anyone can view the list; just go to www.ieee.org and search for *EtherType*.)

For example, a host can send one Ethernet frame with an IPv4 packet and the next Ethernet frame with an IPv6 packet. Each frame would have a different Ethernet Type field value, using the values reserved by the IEEE, as shown in Figure 2-16.

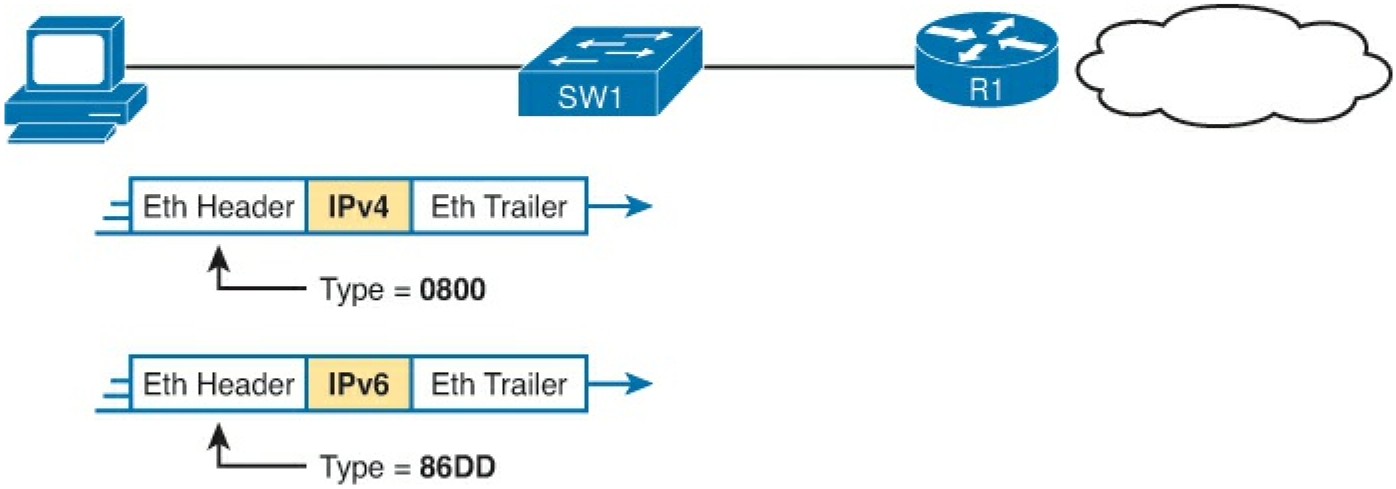


Figure 2-16. Use of Ethernet Type Field

Error Detection with FCS

Ethernet also defines a way for nodes to find out whether a frame's bits changed while crossing over an Ethernet link. (Usually, the bits could change because of some kind of electrical interference, or a bad NIC.) Ethernet, like most every other data link protocol covered on the CCNA exams, uses a field in the data link trailer for the purpose of error detection.

The Ethernet *Frame Check Sequence (FCS)* field in the Ethernet trailer—the only field in the Ethernet trailer—gives the receiving node a way to compare results with the sender, to discover whether errors occurred in the frame. The sender applies a complex math formula to the frame before sending it, storing the result of the formula in the FCS field. The receiver applies the same math formula to the received frame. The receiver then compares its own results with the sender's results. If the results are the same, the frame did not change; otherwise, an error occurred, and the receiver discards the frame.

Note that *error detection* does not also mean *error recovery*. Ethernet defines that the errored frame should be discarded, but Ethernet does not attempt to recover the lost frame. Other protocols, notably TCP, recover the lost data by noticing that it is lost and sending the data again.

Sending Ethernet Frames with Switches and Hubs

Ethernet LANs behave slightly differently depending on whether the LAN has mostly modern devices, in particular, LAN switches instead of some older LAN devices called LAN hubs. Basically, the use of more modern switches allows the use of full-duplex logic, which is much faster and simpler than half-duplex logic, which is required when using hubs. The final topic in this chapter looks at these basic differences.

Sending in Modern Ethernet LANs Using Full-Duplex

Modern Ethernet LANs use a variety of Ethernet physical standards, but with standard Ethernet frames that can flow over any of these types of physical links. Each individual link can run at a different speed, but each link allows the attached nodes to send the bits in the frame to the next node. They must work together to deliver the data from the sending Ethernet node to the destination node.

The process is relatively simple, on purpose; the simplicity lets each device send a large number of frames per second. Figure 2-17 shows an example, in which PC1 sends an Ethernet frame to PC2.

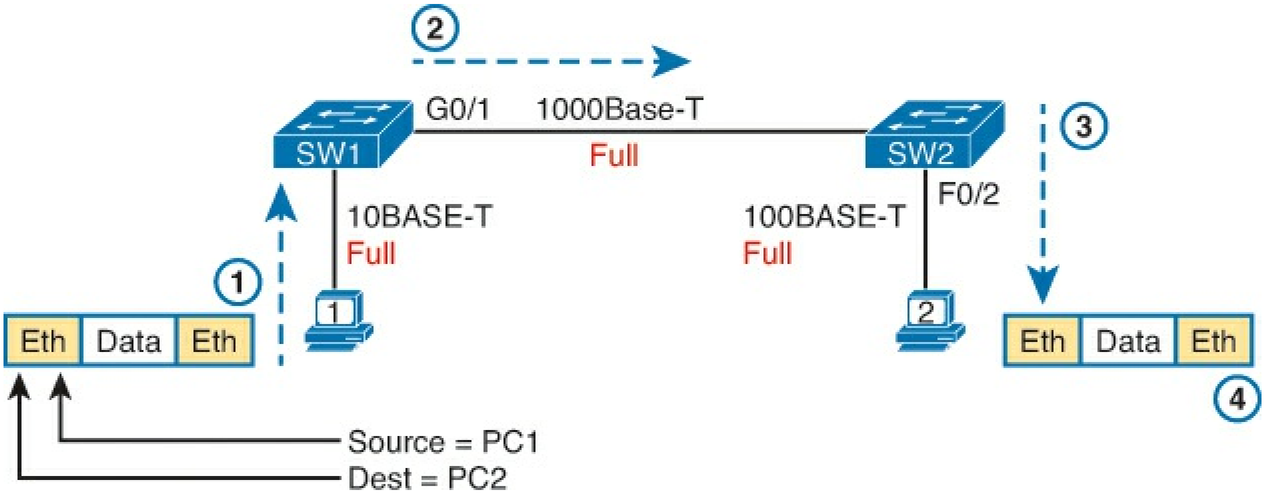


Figure 2-17. Example of Sending Data in a Modern Ethernet LAN

Following the steps in the figure:

1. PC1 builds and sends the original Ethernet frame, using its own MAC address as the source address and PC2's MAC address as the destination address.
2. Switch SW1 receives and forwards the Ethernet frame out its G0/1 interface (short for Gigabit interface 0/1) to SW2.
3. Switch SW2 receives and forwards the Ethernet frame out its F0/2 interface (short for Fast Ethernet interface 0/2) to PC2.
4. PC2 receives the frame, recognizes the destination MAC address as its own, and processes the frame.

The Ethernet network in Figure 2-17 uses full-duplex on each link, but the concept might be difficult to see. Full-duplex means that that the NIC or switch port has no half-duplex restrictions. So, to understand full-duplex, you need to understand half-duplex, as follows:

Key Topic

Half-duplex: Logic in which a port sends data only when it is not also receiving data; in other words, it cannot send and receive at the same time.

Full-duplex: The absence of the half-duplex restriction.

So, with all PCs and LAN switches, and no LAN hubs, all the nodes can use full-duplex. All nodes can send and receive on their port at the same instant in time. For example, in Figure 2-17, PC1 and PC2 could send frames to each other simultaneously, in both directions, without any half-duplex restrictions.

Using Half-Duplex with LAN Hubs

To understand the need for half-duplex logic in some cases, you have to understand a little about an older type of networking device called a LAN hub. When the IEEE first introduced 10BASE-T in 1990, the Ethernet did not yet include LAN switches. Instead of switches, vendors created LAN hubs. The LAN hub provided a number of RJ-45 ports as a place to connect links to PCs, just like a LAN switch, but it used different rules for forwarding data.

LAN hubs forward data using physical layer standards, and are therefore considered to be Layer 1 devices. When an electrical signal comes in one hub port, the hub repeats that electrical signal out all other ports (except the incoming port). By doing so, the data reaches all the rest of the nodes connected to the hub, so the data hopefully reaches the correct destination. The hub has no concept of Ethernet frames, of addresses, and so on.

The downside of using LAN hubs is that if two or more devices transmitted a signal at the same instant, the electrical signal collides and becomes garbled. The hub repeats all received electrical signals, even if it receives multiple signals at the same time. For example, Figure 2-18 shows the idea, with PCs Archie and Bob sending an electrical signal at the same instant of time (at Steps 1A and 1B) and the hub repeating both electrical signals out toward Archie on the left (Step 2).

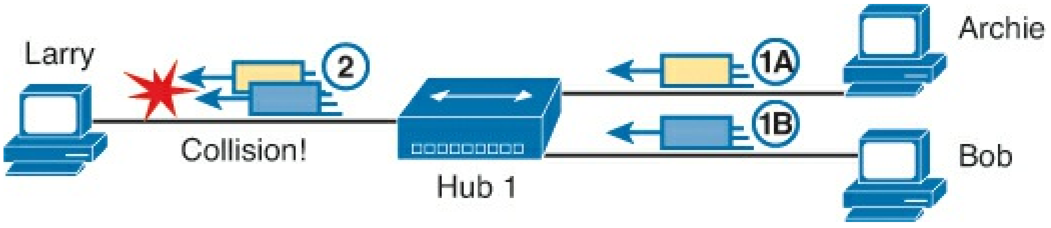


Figure 2-18. Collision Occurring Because of LAN Hub Behavior

Note

For completeness, note that the hub floods each frame out all other ports (except the incoming port). So, Archie's frame goes to both Larry and Bob; Bob's frame goes to Larry and Archie.

If you replace the hub in Figure 2-18 with a LAN switch, the switch prevents the collision on the left. The switch operates as a Layer 2 device, meaning that it looks at the data link header and trailer. A switch would look at the MAC addresses, and even if the switch needed to forward both frames to Larry on the left, the switch would send one frame and queue the other frame until the first frame was finished.

Now back to the issue created by the hub's logic: collisions. To prevent these collisions, the Ethernet nodes must use half-duplex logic instead of full-duplex logic. A problem only occurs when two or more devices send at the same time; half-duplex logic tells the nodes that if someone else is sending, wait before sending.

For example, back in Figure 2-18, imagine that Archie began sending his frame early enough so that Bob received the first bits of that frame before Bob tried to send his own frame. Bob, at Step 1B, would notice that he was receiving a frame from someone else, and using half-duplex logic, would simply wait to send the frame listed at Step 1B.

Nodes that use half-duplex logic actually use a relatively well-known algorithm called CSMA/CD (carrier sense multiple access with collision detection). The algorithm takes care of the obvious cases but also the cases caused by unfortunate timing. For example, two nodes could check for an incoming frame at the exact same instant, both realize that no other node is sending, and both send their frames at the exact same instant, causing a collision. CSMA/CD covers these cases as well, as follows:

Step 1. A device with a frame to send listens until the Ethernet is not busy.

Step 2. When the Ethernet is not busy, the sender begins sending the frame.

Step 3. The sender listens while sending to discover whether a collision occurs; collisions might be caused by many reasons, including unfortunate timing. If a collision occurs, all currently sending nodes do the following:

  A. They send a jamming signal that tells all nodes that a collision happened.

  B. They independently choose a random time to wait before trying again, to avoid unfortunate timing

  C. The next attempt starts again at Step 1.

Although most modern LANs do not often use hubs, and therefore do not need to use half-duplex, enough old hubs still exist in enterprise networks so that you need to be ready to understand duplex issues. Each NIC and switch port has a duplex setting. For all links between PCs and switches, or between switches, use full-duplex. However, for any link connected to a LAN hub, the connected LAN switch and NIC port should use half-duplex. Note that the hub itself does not use half-duplex logic, instead just repeating incoming signals out every other port.

Figure 2-19 shows an example, with full-duplex links on the left and a single LAN hub on the right. The hub then requires SW2's F0/2 interface to use half-duplex logic, along with the PCs connected to the hub.

Key Topic

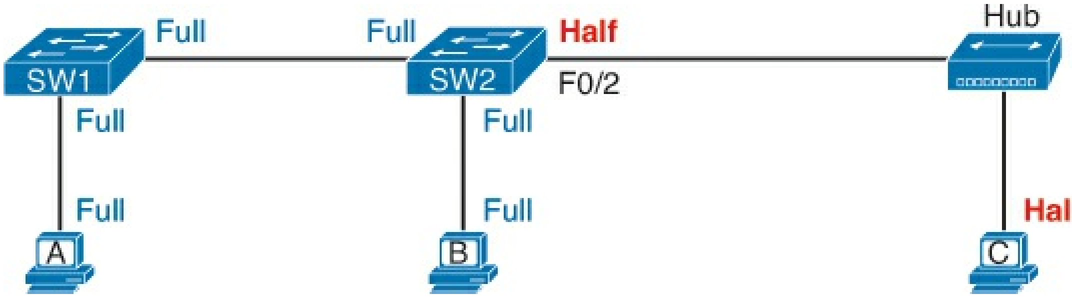


Figure 2-19. Full-and Half-Duplex in an Ethernet LAN

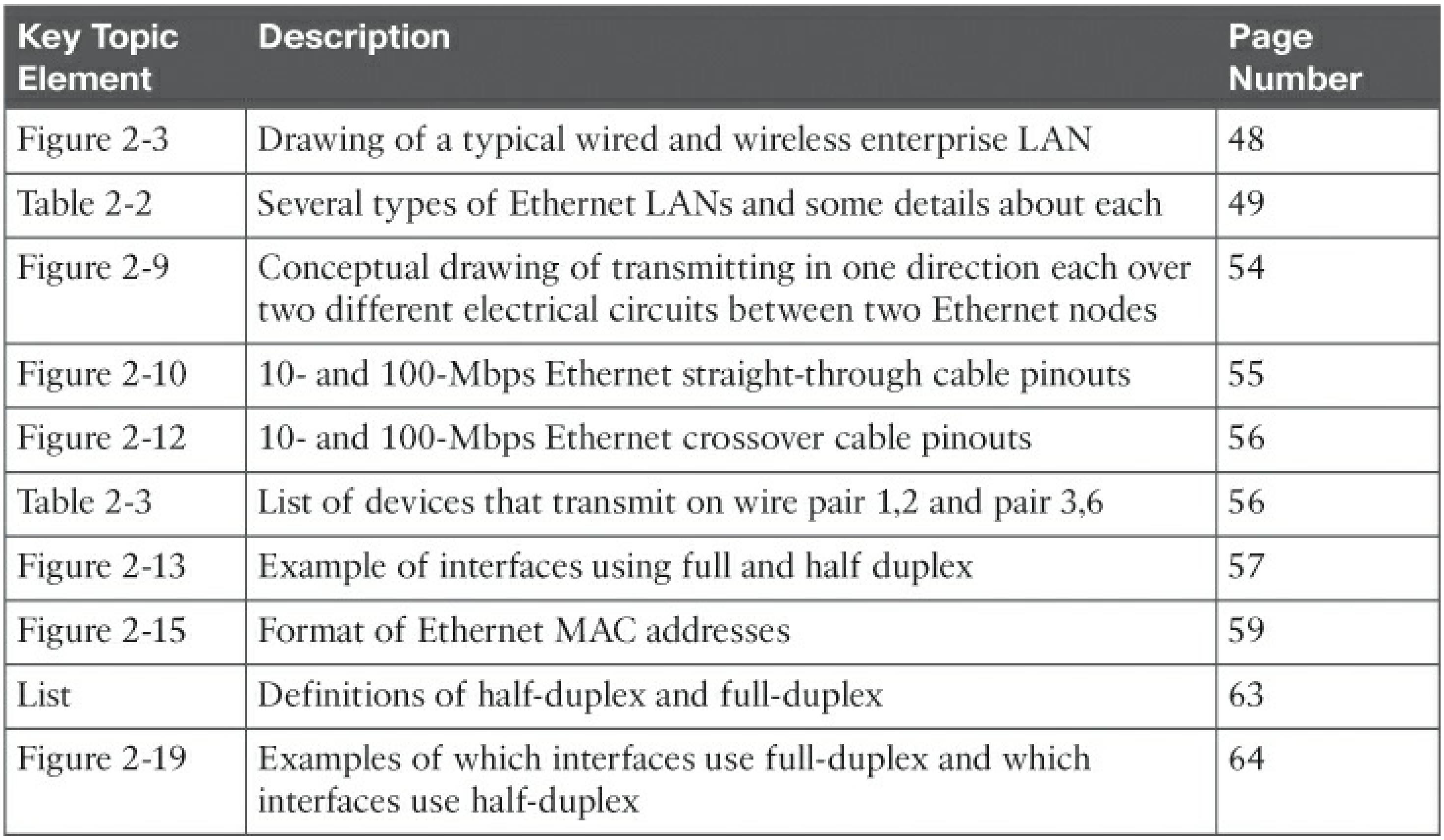
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 2-6 lists these key topics and where each is discussed.

Key Topic

Table 2-6. Key Topics for Chapter 2



Key Topic Element	Description	Page Number
Figure 2-3	Drawing of a typical wired and wireless enterprise LAN	48
Table 2-2	Several types of Ethernet LANs and some details about each	49
Figure 2-9	Conceptual drawing of transmitting in one direction each over two different electrical circuits between two Ethernet nodes	54
Figure 2-10	10- and 100-Mbps Ethernet straight-through cable pinouts	55
Figure 2-12	10- and 100-Mbps Ethernet crossover cable pinouts	56
Table 2-3	List of devices that transmit on wire pair 1,2 and pair 3,6	56
Figure 2-13	Example of interfaces using full and half duplex	57
Figure 2-15	Format of Ethernet MAC addresses	59
List	Definitions of half-duplex and full-duplex	63
Figure 2-19	Examples of which interfaces use full-duplex and which interfaces use half-duplex	64

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists for you to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

Ethernet
IEEE
wired LAN
wireless LAN
Ethernet frame
10BASE-T
100BASE-T
1000BASE-T
Fast Ethernet
Gigabit Ethernet
Ethernet link
RJ-45
Ethernet port
network interface card (NIC)
straight-through cable
crossover cable
Ethernet address

MAC address
unicast address
broadcast address
Frame Check Sequence

Chapter 3. Fundamentals of WANs

This chapter covers the following exam topics:

Operation of IP Data Networks

Recognize the purpose and functions of various network devices such as Routers, Switches, Bridges and Hubs.

Select the components required to meet a given network specification.

Predict the data flow between two hosts across a network.

Most Layer 1 and 2 networking technology falls into one of two primary categories: wide-area networks (WAN) and LANs. Because both WANs and LANs match OSI Layers 1 and 2, they have many similarities: Both define cabling details, transmission speeds, encoding, and how to send data over physical links, as well as data link frames and forwarding logic.

Of course, WANs and LANs have many differences as well, most notably the distances between nodes and the business model for paying for the network. First, in terms of the distance, the terms *local* and *wide* give us a small hint: LANs typically include nearby devices, while WANs connect devices that can be far apart, potentially hundreds or thousands of miles apart.

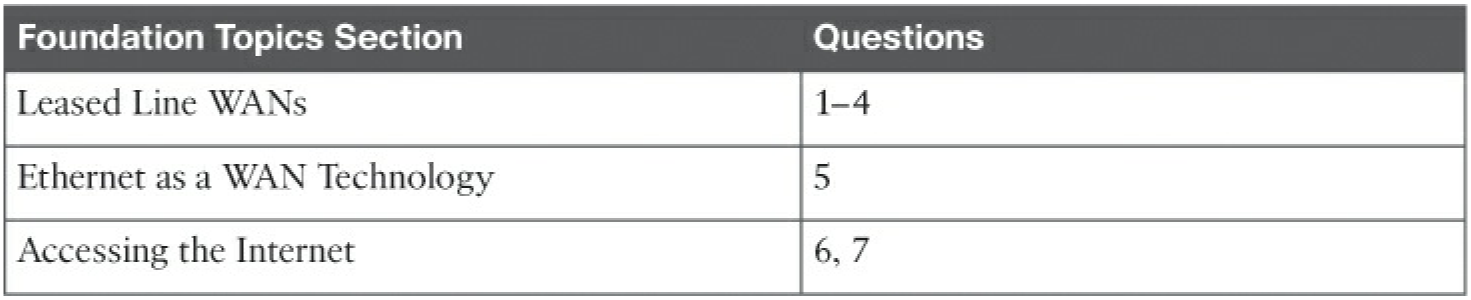
The other big difference between the two is this: You pay for and own LANs, but you lease WANs. With LANs, you buy the cables and LAN switches and install them in spaces you control. WANs physically pass through other people's property, and you do not have the right to put your cables and devices there. So, a few companies, like a telephone company or cable company, install and own their own devices and cables, creating their own networks, and lease the right to send data over their networks.

This chapter introduces WANs in three major sections. The first introduces leased line WANs, a type of WAN link that has been part of enterprise networks since the 1960s. The second part shows how Ethernet can be used to create WAN services by taking advantage of the longer cable length possibilities of modern fiber-optic Ethernet standards. The last part of the chapter takes a survey of common WAN technology used to access the Internet.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 3-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Leased Line WANs	1–4
Ethernet as a WAN Technology	5
Accessing the Internet	6, 7

1. Which of the following best describes the main function of OSI Layer 1 as used in WANs?

- **a.** Framing
- **b.** Delivery of bits from one device to another
- **c.** Addressing
- **d.** Error detection

2. In the cabling for a leased line, which of the following typically connects to a four-wire line provided by a telco?

- **a.** Router serial interface without internal CSU/DSU
- **b.** CSU/DSU
- **c.** Router serial interface with internal transceiver
- **d.** Switch serial interface

3. Which of the following is an accurate speed at which a leased line can operate in the United States?

- **a.** 100 Mbps
- **b.** 100 Kbps
- **c.** 256 Kbps
- **d.** 6.4 Mbps

4. Which of the following fields in the HDLC header used by Cisco routers does Cisco add, beyond the ISO standard HDLC?

- **a.** Flag
- **b.** Type

   c. Address

   d. FCS

5. Two routers, R1 and R2, connect using an Ethernet over MPLS service. The service provides point-to-point service between these two routers only, as a Layer 2 Ethernet service. Which of the following are the most likely to be true about this WAN? (Choose two answers.)

   a. R1 will connect to a physical Ethernet link, with the other end of the cable connected to R2.

   b. R1 will connect to a physical Ethernet link, with the other end of the cable connected to a device at the WAN service provider point of presence.

   c. R1 will forward data link frames to R2 using an HDLC header/trailer.

   d. R1 will forward data link frames to R2 using an Ethernet header/trailer.

6. Which of the following Internet access technologies, used to connect a site to an ISP, offers asymmetric speeds? (Choose two answers.)

   a. Leased lines

   b. DSL

   c. Cable Internet

   d. BGP

7. Fred has just added DSL service at his home, with a separate DSL modem and consumer-grade router with four Ethernet ports. Fred wants to use the same old phone he was using before the installation of DSL. Which is most likely true about the phone cabling and phone used with his new DSL installation?

   a. He uses the old phone, cabled to one of the router/switch device’s Ethernet ports.

   b. He uses the old phone, cabled to the DSL modem’s ports.

   c. He uses the old phone, cabled to an existing telephone port, and not to any new device.

   d. The old phone must be replaced with a digital phone.

Answers to the “Do I Know This Already?” quiz:

1 B **2** B **3** C **4** B **5** B and D **6** B and C **7** C

Foundation Topics

Leased Line WANs

Imagine that you are the primary network engineer for an enterprise TCP/IP internetwork. Your company is building a new building at a site 100 miles away from your corporate headquarters. You will of course install a LAN throughout the new building, but you also need to connect that new remote LAN to the rest of the existing enterprise TCP/IP network.

To connect the new building’s LAN to the rest of the existing corporate network, you need some kind of a WAN. At a minimum, that WAN needs to be able to send data from the remote LAN back to the rest of the existing network and vice versa. Leased line WANs do exactly that, forwarding data between two routers.

From a basic point of view, a leased line WAN works a lot like an Ethernet crossover cable connecting two routers, but with few distance limitations. Each router can send at any time (full-duplex) over the leased line, for tens, hundreds, or even thousands of miles.

This section begins by giving some perspective about where leased lines fit with LANs and routers, because one main goal for a WAN is to move data between LANs. The rest of this first section explains the physical details about leased lines, followed with information about data link protocols.

Positioning Leased Lines with LANs and Routers

The vast majority of end-user devices in an enterprise or SOHO network connect directly into a LAN. Many PCs use an Ethernet NIC that connects to a switch. More and more, devices use 802.11 wireless LANs, with some devices like phones and tablets supporting only wireless LAN connections.

Now think about a typical company that has many different locations. From a human resources perspective, it might have lots of employees that work at many locations. From a facilities perspective, the company might have a few large sites, with hundreds or even thousands of individual branch offices, stores, or other small locations. However, from a networking perspective, think of each site as being one or more LANs that need to communicate with each other, and to communicate, those LANs need to be connected to each other using a WAN.

To connect LANs together using a WAN, the internetwork uses a router connected to each LAN, with a WAN link between the routers. First, the enterprise's network engineer would order some kind of WAN link. A router at each site connects to both the WAN link and the LAN, as shown in Figure 3-1. Note that crooked line between the routers is the common way to represent a leased line when the drawing does not need to show any of the physical details of the line.

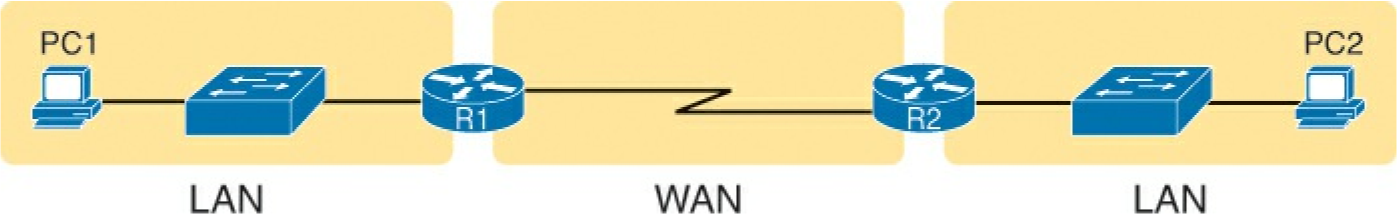


Figure 3-1. Small Enterprise Network with One Leased Line

The world of WAN technologies includes many different options in addition to the leased line shown in the figure. WAN technology includes a large number of options for physical links, as well as the data link protocols that control those links. By comparison, the wired LAN world basically has one major option today—Ethernet—because Ethernet won the wired LAN battle in the marketplace back in the 1980s and 1990s.

Physical Details of Leased Lines

The leased line service delivers bits in both directions, at a predetermined speed, using full-duplex logic. In fact, conceptually it acts as if you had a full-duplex crossover Ethernet link between two routers, as shown in Figure 3-2. The leased line uses two pair of wires, one pair for each direction of sending data, which allows full-duplex operation.

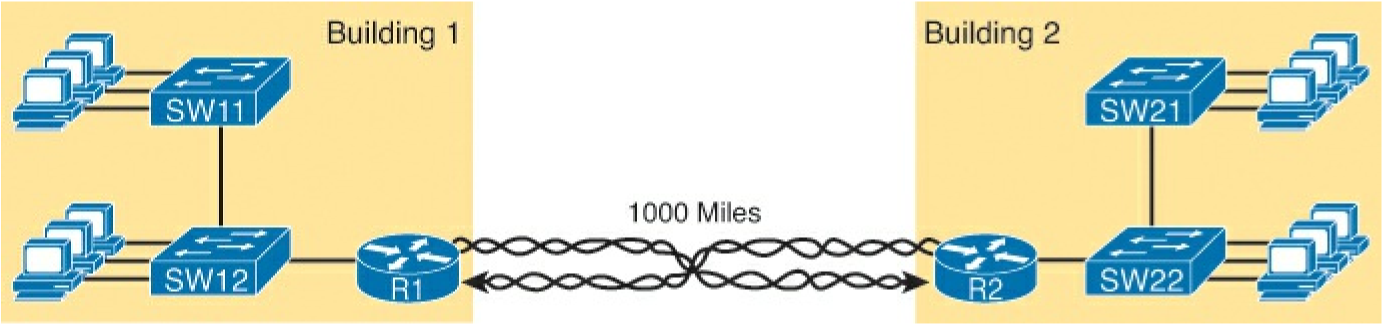


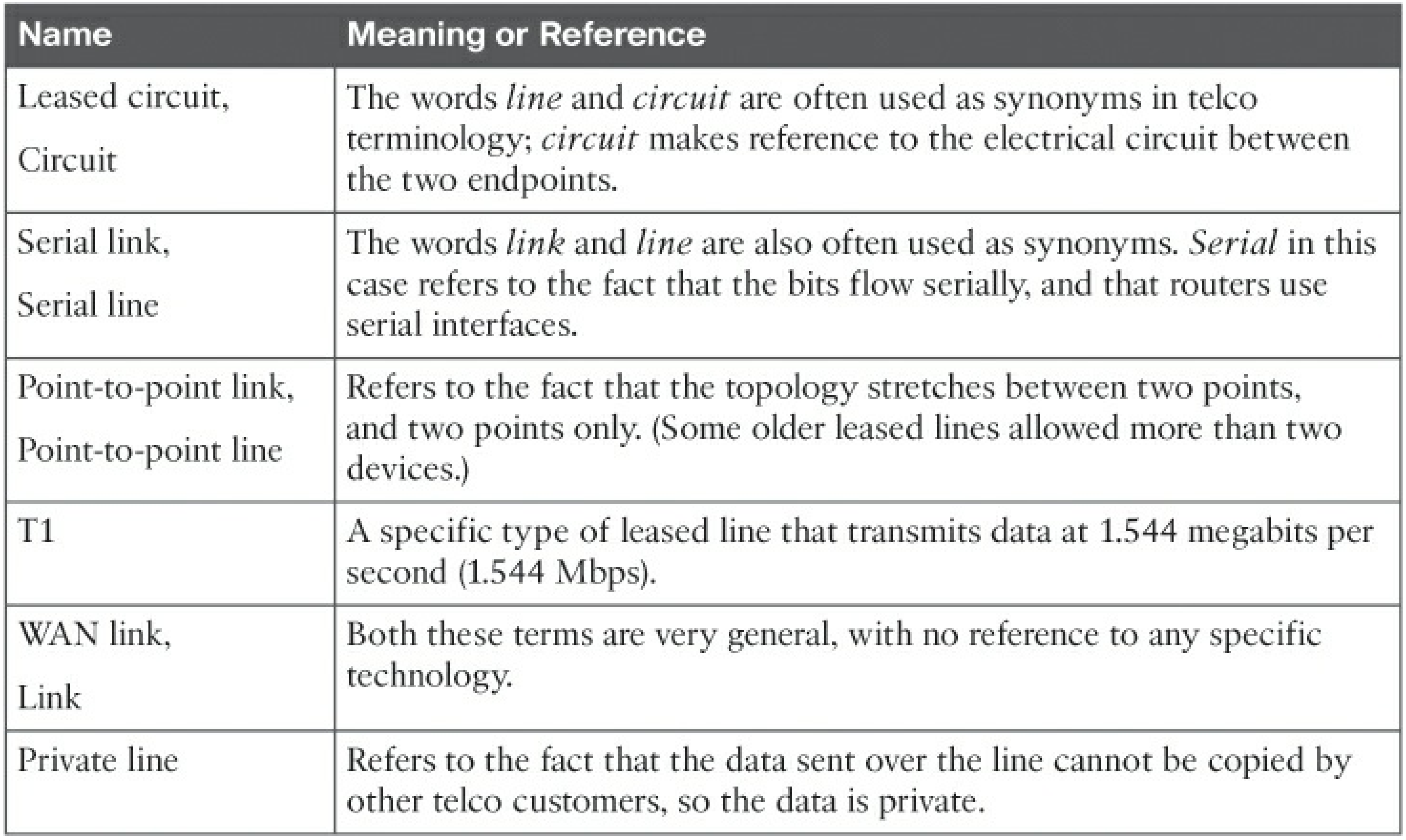
Figure 3-2. Conceptual View of the Leased Line Service

Of course, leased lines have many differences compared to an Ethernet crossover cable. To create such possibly long links, or circuits, a leased line does not actually exist as a single long cable between the two sites. Instead, the telco installs a large network of cables and specialized switching devices to create its own computer network. The telco network creates a service that acts like a crossover cable between two points, but the physical reality is hidden from the customer.

Leased lines come with their own set of terminology as well. First, the term *leased line* refers to the fact that the company using the leased line does not own the line, but instead pays a monthly lease fee to use it. However, many people today use the generic term *service provider* to refer to a company that provides any form of WAN connectivity, including Internet services.

Given its long history, leased lines have had many names. Table 3-2 lists some of those names, mainly so that in a networking job, you have a chance to translate from the terms each person uses with a basic description as to the meaning of the name.

Table 3-2. Different Names for a Leased Line



Name	Meaning or Reference
Leased circuit, Circuit	The words *line* and *circuit* are often used as synonyms in telco terminology; *circuit* makes reference to the electrical circuit between the two endpoints.
Serial link, Serial line	The words *link* and *line* are also often used as synonyms. *Serial* in this case refers to the fact that the bits flow serially, and that routers use serial interfaces.
Point-to-point link, Point-to-point line	Refers to the fact that the topology stretches between two points, and two points only. (Some older leased lines allowed more than two devices.)
T1	A specific type of leased line that transmits data at 1.544 megabits per second (1.544 Mbps).
WAN link, Link	Both these terms are very general, with no reference to any specific technology.
Private line	Refers to the fact that the data sent over the line cannot be copied by other telco customers, so the data is private.

Leased Line Cabling

To create a leased line, some physical path must exist between the two routers on the ends of the link. The physical cabling must leave the buildings where each router sits. However, the telco does not simply install one cable between the two buildings. Instead, it uses what is typically a large and complex network that creates the appearance of a cable between the two routers.

Figure 3-3 gives a little insight into the cabling that could exist inside the telco for a short leased line. Telcos put their equipment in buildings called central offices (CO). The telco installs cables from the CO to most every other building in the city, expecting to sell services to the people in those buildings one day. The telco would then configure its switches to use some of the capacity on each cable to send data in both directions, creating the equivalent of a crossover cable between the two routers.

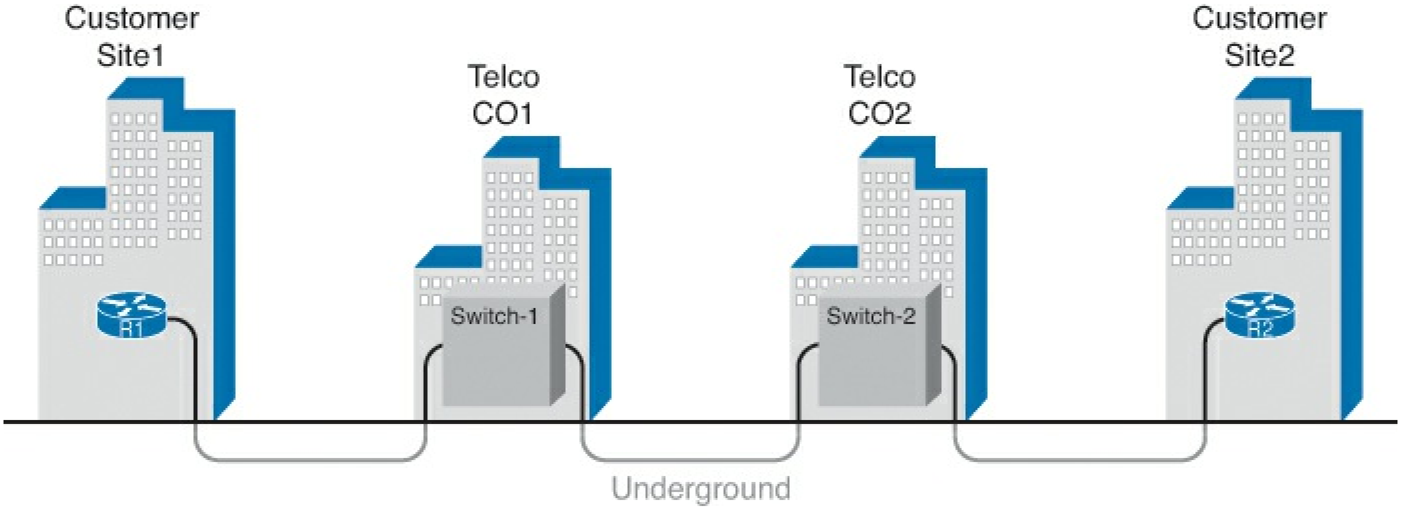


Figure 3-3. Possible Cabling Inside a Telco for a Short Leased Line

Although what happens inside the telco is completely hidden from the telco customer, enterprise engineers do need to know about the parts of the link that exist inside the customer's building at the router.

First, each site has *customer premises equipment (CPE)*, which includes the router, serial interface card, and CSU/DSU. Each router uses a serial interface card that acts somewhat like an Ethernet NIC, sending and receiving data over the physical link. The physical link requires a function called a channel service unit/data service unit (CSU/DSU). The CSU/DSU can either be integrated into the serial interface card in the router or sit outside the router as an external device. Figure 3-4 shows the CPE devices, along with the cabling.

Key Topic

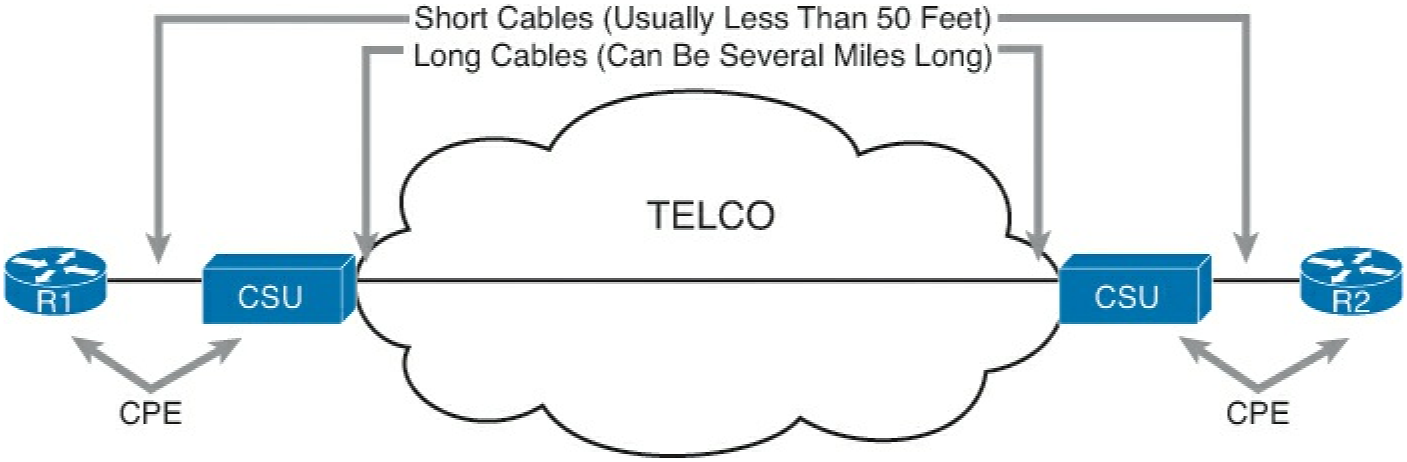

Short Cables (Usually Less Than 50 Feet)
Long Cables (Can Be Several Miles Long)
TELCO
R1
CSU
CSU
R2
CPE
CPE

Figure 3-4. Point-to-Point Leased Line: Components and Terminology

The cabling includes a short serial cable (only if an external CSU/DSU is used) plus the cable installed by the telco for the leased line itself. The serial cable connects the router serial interface to the external CSU/DSU. (Many cable options exist; the cable just needs to match the connector of the serial interface on one end and the CSU/DSU on the other end.) The four-wire cable from the telco plugs into the CSU/DSU, typically using an RJ-48 connector that has the same size and shape as an RJ-45 connector (as seen in Chapter 2's Figure 2-7).

Telcos offer a wide variety of speeds for leased lines. However, you cannot pick the exact speed you want; instead, you must pick from a long list of predefined speeds. Slower-speed links run at multiples of 64 kbps (kilobits per second), while faster links run at multiples of about 1.5 Mbps (megabits per second).

Building a WAN Link in a Lab

On a practical note, to prepare for the CCENT and CCNA exams, you can choose to buy some used router and switch hardware for hands-on practice. If you do, you can create the equivalent of a leased line without a real leased line from a telco, and without CSU/DSUs, just using a cabling trick. This short topic tells you enough information to create a WAN link in your home lab.

First, the serial cables normally used between a router and an external CSU/DSU are called *data terminal equipment (DTE) cables*. To create a physical WAN link in a lab, you need two serial cables: one serial DTE cable, plus a similar but slightly different matching *data communications equipment (DCE) cable*. The DCE cable has a female connector, while the DTE cable has a male connector, which allows the two cables to be attached directly. The DCE cable also does the equivalent task of an Ethernet crossover cable by swapping the transmit and receive wire pairs, as shown in Figure 3-5.

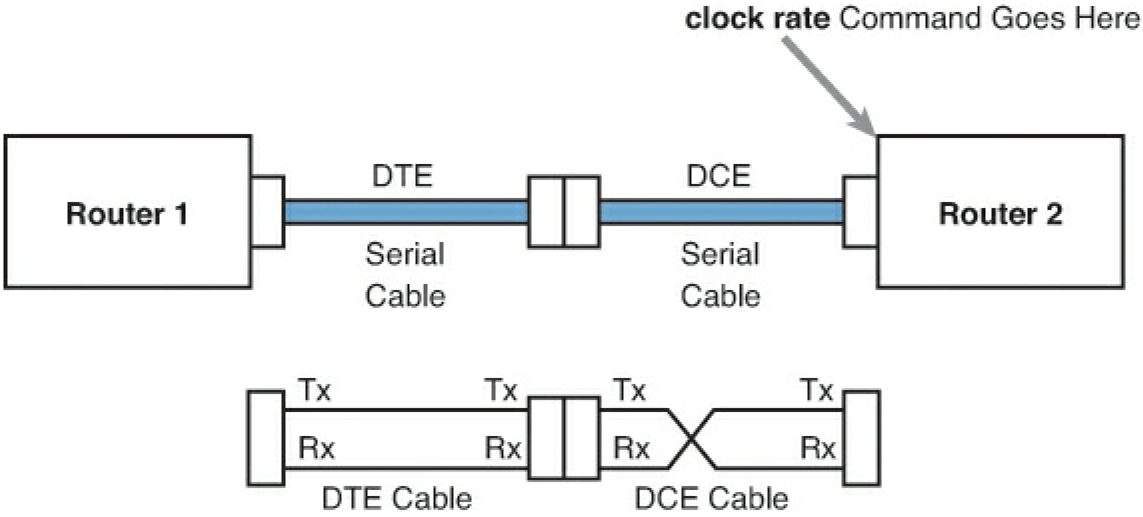


Figure 3-5. Serial Cabling Uses a DTE Cable and a DCE Cable

The figure shows the cable details at the top, with the wiring details inside the cable at the bottom. In particular, at the bottom of the figure, note that the DTE serial cable acts as a straight-through cable, and does not swap the transmit and receive pair, while the DCE cable does swap the pairs.

Finally, to make the link work, the router with the DCE cable installed must do one function normally done by the CSU/DSU. The CSU/DSU normally provides a function called *clocking*, in which it tells the router exactly when to send each bit through signaling over the serial cable. A router serial interface can provide clocking, but the router does not do so unless configured with the **clock rate** command. Chapter 15's section "Bandwidth and Clock Rate on Serial Interfaces" shows a sample configuration.

Data Link Details of Leased Lines

A leased line provides a Layer 1 service. In other words, it promises to deliver bits between the devices connected to the leased line. However, the leased line itself does not define a data link layer protocol to be used on the leased line.

Because leased lines define only the Layer 1 transmission service, many companies and standards organizations have created data link protocols to control and use leased lines. Today, the two most popular data link layer protocols used for leased lines between two routers are High-Level Data Link Control (HDLC) and Point-to-Point Protocol (PPP). This next topic takes a brief look at HDLC, just to show one example, plus a few comments about how routers use WAN data link protocols.

HDLC Basics

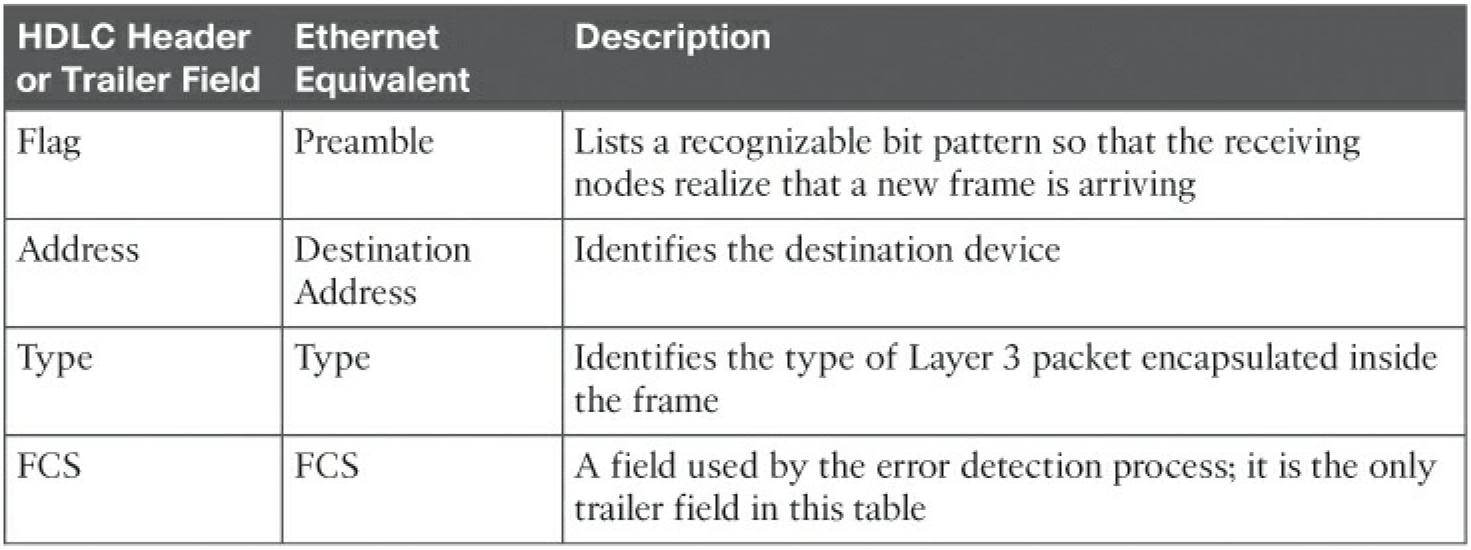
All data link protocols perform a similar role: to control the correct delivery of data over a physical link of a particular type. For example, the Ethernet data link protocol uses a destination address field to identify the correct device that should receive the data, and an FCS field that allows the receiving device to determine whether the data arrived correctly. HDLC provides similar functions.

HDLC has less work to do because of the simple point-to-point topology of a point-to-point leased line. When one router sends an HDLC frame, it can only go one place: to the other end of the link. So, while HDLC has an address field, the destination is implied. The idea is sort of like when I have lunch with my friend Gary, and only Gary. I do not need to start every sentence with "Hey Gary"—he knows I am talking to him.

> **Note**
>
> In case you wonder why HDLC has an address field at all, in years past, the telcos offered multidrop circuits. These circuits included more than two devices, so there was more than one possible destination, requiring an address field to identify the correct destination.

HDLC has other fields and functions similar to Ethernet as well. Table 3-3 lists the HDLC fields, with the similar Ethernet header/trailer field, just for the sake of learning HDLC based on something you have already learned about (Ethernet).

Table 3-3. Comparing HDLC Header Fields to Ethernet



HDLC Header or Trailer Field	Ethernet Equivalent	Description
Flag	Preamble	Lists a recognizable bit pattern so that the receiving nodes realize that a new frame is arriving
Address	Destination Address	Identifies the destination device
Type	Type	Identifies the type of Layer 3 packet encapsulated inside the frame
FCS	FCS	A field used by the error detection process; it is the only trailer field in this table

HDLC exists today as a standard of the International Organization for Standardization (ISO), the same organization that brought us the OSI model. However, ISO standard HDLC does not have a Type field, and routers need to know the type of packet inside the frame. So, Cisco routers use a Cisco-proprietary variation of HDLC that adds a Type field, as shown in Figure 3-6.

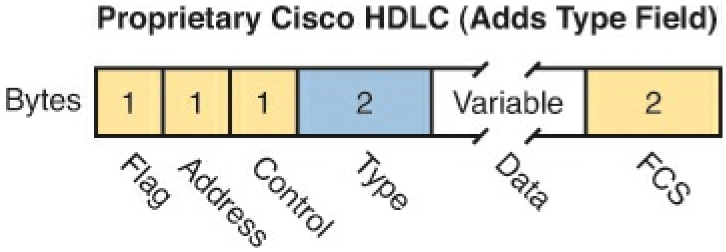


Figure 3-6. HDLC Framing

How Routers Use a WAN Data Link

Today, most leased lines connect to routers, and routers focus on delivering packets to a destination host. However, routers physically connect to both LANs and WANs, with those LANs and WANs requiring that data be sent inside data link frames. So, now that you know a little about HDLC, it helps to think about how routers use the HDLC protocol when sending data.

First, the TCP/IP network layer focuses on forwarding IP packets from the sending host to the destination host. The underlying LANs and WANs just act as a way to move the packets to the next router or end-user device. Figure 3-7 shows that network layer perspective.

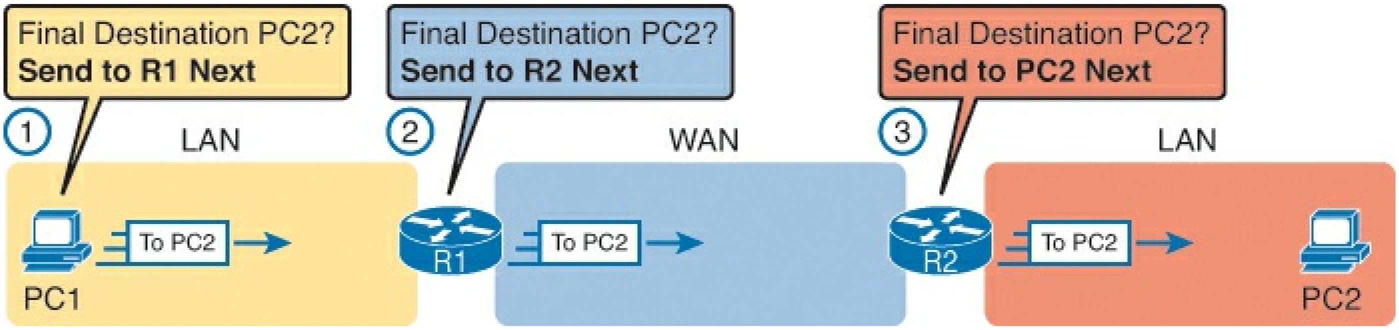


Figure 3-7. IP Routing Logic over LANs and WANs

Following the steps in the figure, for a packet sent by PC1 to PC2's IP address:

1. PC1's network layer (IP) logic tells it to send the packet to a nearby router (R1).
2. Router R1's network layer logic tells it to forward (route) the packet out the leased line to router R2 next.
3. Router R2's network layer logic tells it to forward (route) the packet out the LAN link to PC2 next.

While Figure 3-7 shows the network layer logic, the PCs and routers must rely on the LANs and WANs in the figure to actually move the bits in the packet. Figure 3-8 shows the same figure, with the same packet, but this time showing some of the data link layer logic used by the hosts and routers. Basically, three separate data link layer steps encapsulate the packet, inside a data link frame, over three hops through the internetwork: from PC1 to R1, from R1 to R2, and from R2 to PC2.

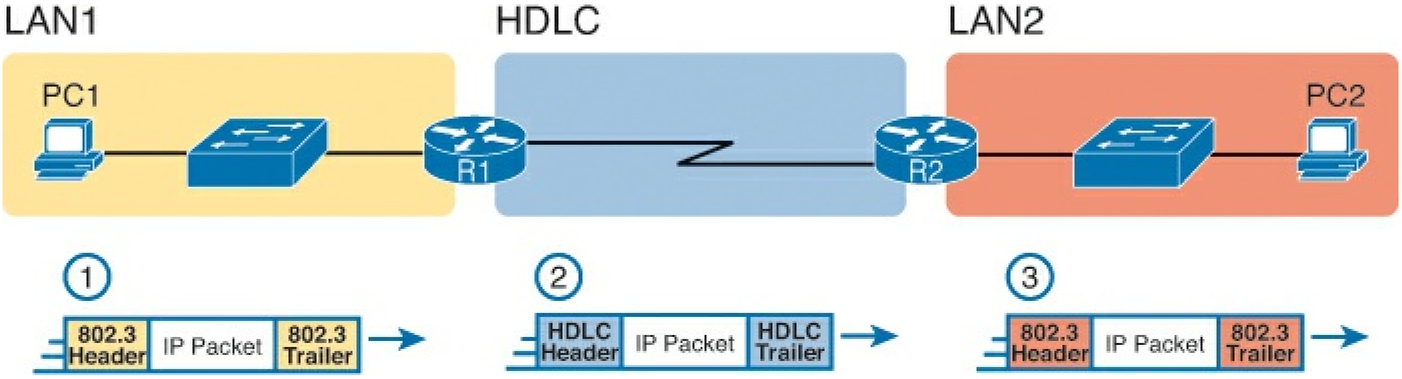


Figure 3-8. General Concept of Routers Deencapsulating and Reencapsulating IP Packets

Following the steps in the figure, again for a packet sent by PC1 to PC2's IP address:

1. To send the IP packet to router R1 next, PC1 encapsulates the IP packet in an Ethernet frame that has the destination MAC address of R1.
2. Router R1 deencapsulates (removes) the IP packet from the Ethernet frame, encapsulates the packet into an HDLC frame using an HDLC header and trailer, and forwards the HDLC frame to router R2 next.
3. Router R2 deencapsulates (removes) the IP packet from the HDLC frame, encapsulates the packet into an Ethernet frame that has the destination MAC address of PC2, and forwards the Ethernet frame to PC2.

In summary, a leased line with HDLC creates a WAN link between two routers so that they can forward packets for the devices on the attached LANs. The leased line itself provides the physical means to transmit the bits, in both directions. The HDLC frames provide the means to encapsulate the network layer packet correctly so that it crosses the link between routers.

Leased lines have many benefits that have led to their relatively long life in the WAN marketplace. These lines are simple for the customer, are widely available, are of high quality, and are private. However, they do have some negatives as well compared to newer WAN technologies, including a higher cost and typically longer lead times to get the service installed. The next section looks at an alternative WAN technology used in some examples in this book: Ethernet.

Ethernet as a WAN Technology

For the first several decades of the existence of Ethernet, Ethernet was only appropriate for LANs. The restrictions on cable lengths and devices might allow a LAN that stretched a kilometer or two, to support a campus LAN, but that was the limit.

As time passed, the IEEE improved Ethernet standards in ways that made Ethernet a reasonable WAN technology. For example, the 1000BASE-LX standard uses single-mode fiber cabling, with support for a 5-km cable length; the 1000BASE-ZX standard supports an even longer 70-km cable length. As time went by, and as the IEEE improved cabling distances for fiber Ethernet links, Ethernet became a reasonable WAN technology.

Today, in this second decade of the twenty-first century, many WAN service providers (SP) offer WAN services that take advantage of Ethernet. SPs offer a wide variety of these Ethernet WAN services, with many different names. But all of them use a similar model, with Ethernet used between the customer site and the SP's network, as shown in Figure 3-9.

Key Topic

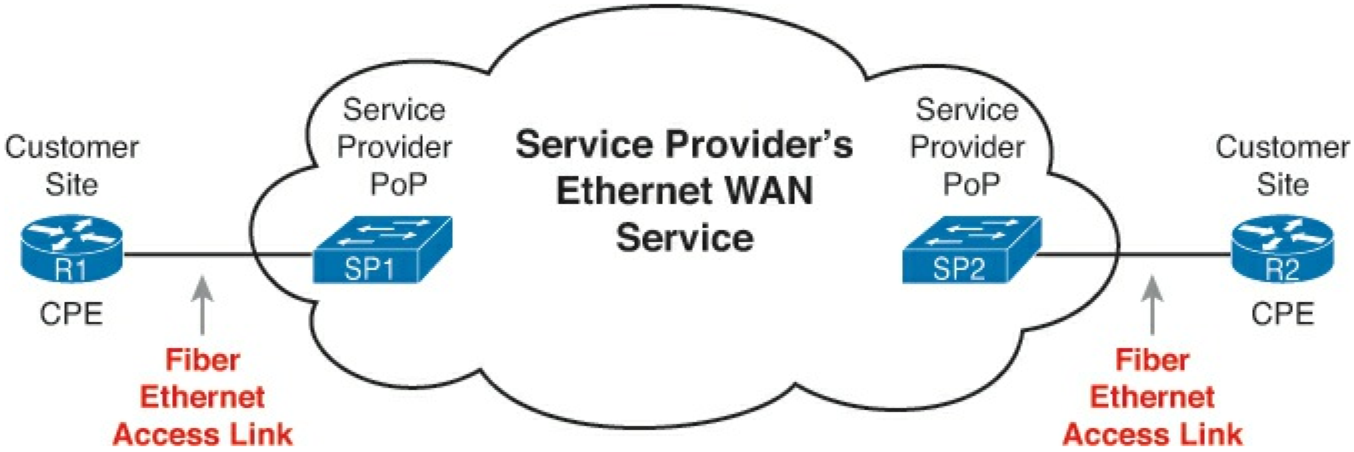

Customer Site
R1
CPE
Fiber Ethernet Access Link
Service Provider PoP
SP1
Service Provider's Ethernet WAN Service
Service Provider PoP
SP2
Customer Site
R2
CPE
Fiber Ethernet Access Link

Figure 3-9. Fiber Ethernet Link to Connect a CPE Router to a Service Provider's WAN

The model shown in Figure 3-9 has many of the same ideas of how a telco creates a leased line, as seen earlier in Figure 3-3, but now with Ethernet links and devices. The customer connects to an Ethernet link using a router interface. The (fiber) Ethernet link leaves the customer building and connects to some nearby SP location called a point of presence (POP). Instead of a telco switch as seen in Figure 3-3, the SP uses an Ethernet switch. Inside the SP's network, the SP uses any technology that it wants to create the specific Ethernet WAN services.

Ethernet WANs that Create a Layer 2 Service

The WAN services implied by Figure 3-9 include a broad number of services, with a lot of complex networking concepts needed to understand those services. Yet, we sit here at the third chapter of what is probably your first Cisco certification book, so clearly, getting into depth on these WAN services makes little sense. So, for the purposes of the CCENT certification, this book focuses on one specific Ethernet WAN service that can be easily understood if you understand how Ethernet LANs work.

> **Note**
>
> For perspective about the broad world of the service provider network shown in Figure 3-9, consider the Cisco certification paths for a moment. Cisco has CCNA, CCNP, and CCIE certifications in many areas: routing and switching, voice, security, and so on. Two paths—Service Provider and Service Provider Operations—focus on technologies and tasks in the service provider arena. See www.cisco.com/go/certifications for more details.

The one Ethernet WAN service used for CCENT and CCNA Routing and Switching examples goes by two names: Ethernet emulation and Ethernet over MPLS (EoMPLS). Ethernet emulation is a general term, meaning that the service acts like one Ethernet link. EoMPLS refers to Multiprotocol Label Switching (MPLS), which is one technology that can be used inside the SP's cloud. This book will refer to this specific service either as Ethernet emulation or EoMPLS.

The type of EoMPLS service discussed in this book gives the customer an Ethernet link between two sites. In other words, the EoMPLS service provides

- A point-to-point connection between two customer devices
- Behavior as if a fiber Ethernet link existed between the two devices

So, if you can imagine two routers, with a single Ethernet link between the two routers, you understand what this particular EoMPLS service does.

Figure 3-10 shows the idea. In this case, the two routers, R1 and R2, connect with an EoMPLS service instead of a serial link. The routers use Ethernet interfaces, and they can send data in both directions at the same time. Physically, each router actually connects to some SP PoP, as shown earlier in Figure 3-9, but logically, the two routers can send Ethernet frames to each other over the link.

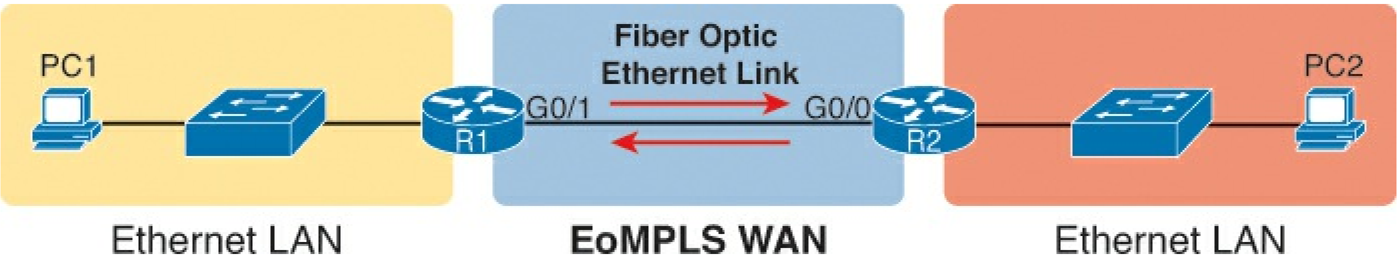


Figure 3-10. EoMPLS Acting Like a Simple Ethernet Link Between Two Routers

How Routers Route IP Packets Using Ethernet Emulation

WANs, by their very nature, give IP routers a way to forward IP packets from a LAN at one site, over the WAN, and to another LAN at another site. Routing over an EoMPLS WAN link still uses the WAN like a WAN, as a way to forward IP packets from one site to another. However, the WAN link happens to use the same Ethernet protocols as the Ethernet LAN links at each site.

The EoMPLS link uses Ethernet for both Layer 1 and Layer 2 functions. That means the link uses the same familiar Ethernet header and trailer, as seen in the middle of Figure 3-11.

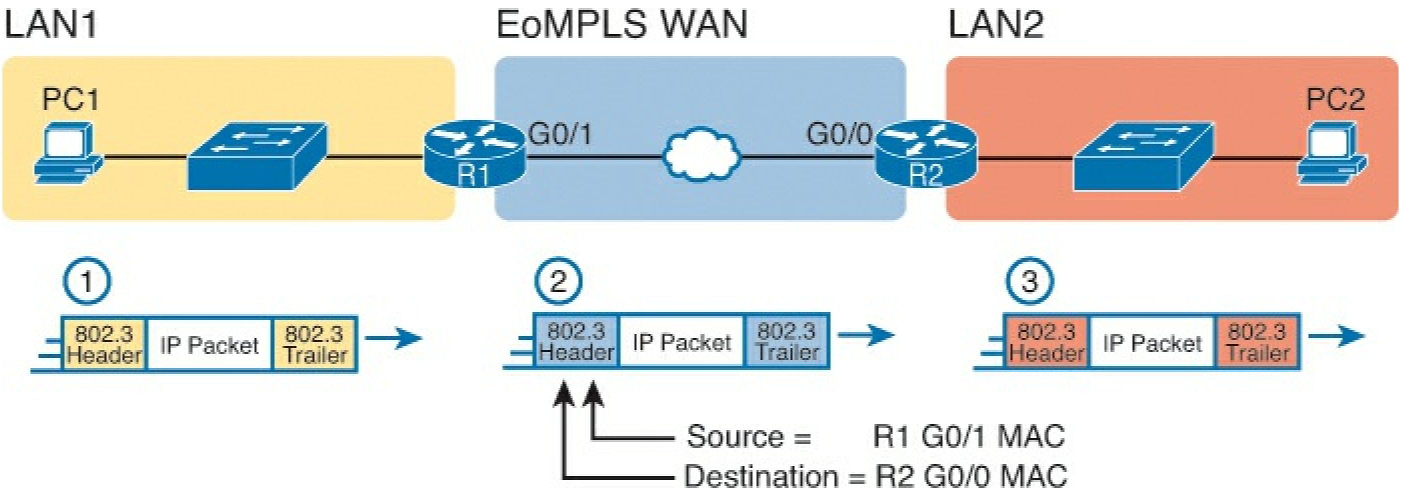


Figure 3-11. Routing over an EoMPLS Link

> **Note**
>
> This book shows EoMPLS connections as a familiar single black line, like other Ethernet links, but with a small cloud overlaid to note that this particular Ethernet link is through an Ethernet WAN service.

The figure shows the same three routing steps as shown with the serial link in the earlier Figure 3-8. In this case, all three routing steps use the same Ethernet (802.3) protocol. However, note that each frame's data link header and trailer are different. Each router discards the old data link header/trailer and adds a new set, as described in these steps. Focus mainly on Step 2, because compared to the similar example shown in Figure 3-8, Steps 1 and 3 are unchanged:

1. To send the IP packet to router R1 next, PC1 encapsulates the IP packet in an Ethernet frame that has the destination MAC address of R1.
2. Router R1 deencapsulates (removes) the IP packet from the Ethernet frame and encapsulates the packet into a new Ethernet frame, with a new Ethernet header and trailer. The destination MAC address is R2's G0/0 MAC address, and the source MAC address is R1's G0/1 MAC address. R1 forwards this frame over the EoMPLS service to R2 next.
3. Router R2 deencapsulates (removes) the IP packet from the HDLC frame, encapsulates the packet into an Ethernet frame that has the destination MAC address of PC2, and forwards the Ethernet frame to PC2.

Accessing the Internet

Many people begin their CCENT and CCNA study never having heard of leased lines, but many people have heard of two other WAN technologies used to gain access to the Internet: digital subscriber line (DSL) and cable. These two WAN technologies do not replace leased lines in all cases, but they do play an important role in the specific case of creating a WAN connection between a home or office and the Internet.

This last major section of the chapter begins by introducing the basic networking concepts behind the Internet, followed with some specifics of how DSL and cable provide a way to send data to/from the Internet.

The Internet as a Large WAN

The Internet is an amazing cultural phenomenon. Most of us use it every day. We post messages on social media sites, we search for information using a search engine like Google, and we send emails. We use apps on our phones to pull down information, like weather reports, maps, and movie reviews. We use the Internet to purchase physical products and to buy and download digital products like music and videos. The Internet has created completely new things to do and changed the old ways of living life compared to a generation ago.

However, if you instead focus on the networking technology that creates the Internet, the Internet is simply one huge TCP/IP network. In fact, the name "Internet" comes from the core network layer protocol: Internet Protocol. The Internet includes many LANs, and because the Internet spans the globe, it of course needs WAN links to connect different sites.

As a network of networks, the Internet is actually owned by countless companies and people. The Internet includes most every enterprise TCP/IP network and a huge number of home-based networks, as well as a huge number of individuals from their phones and other wireless devices, as shown in Figure 3-12.

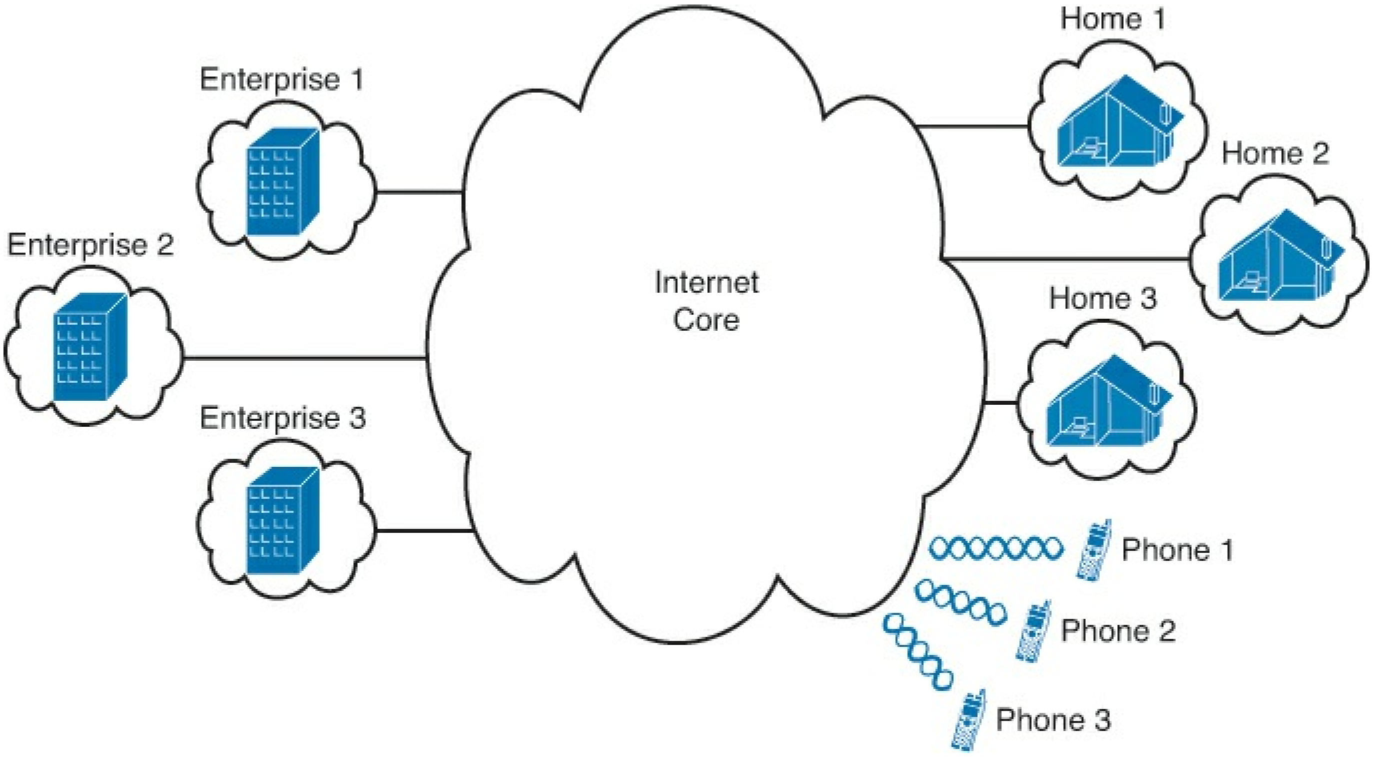

Enterprise 1
Enterprise 2
Enterprise 3
Internet Core
Home 1
Home 2
Home 3
Phone 1
Phone 2
Phone 3

Figure 3-12. Internet with Enterprise, Home, and Phone Subscribers

The middle of the Internet, called the *Internet core*, exists as LANs and WANs owned and operated by Internet service providers (ISP). (Figure 3-12 shows the Internet core as a cloud, because network diagrams show a cloud when hiding the details of a part of the network.) ISPs cooperate to create a mesh of links between each other in the Internet core, so that no matter through which ISP a particular company or person connects, some path exists to every device.

Figure 3-13 shows a slightly different version of Figure 3-12, in this case showing the concept of the Internet core: ISP networks that connect to both their customers, as well as each other, so that IP packets can flow from every customer of every ISP to every other customer of every other ISP.

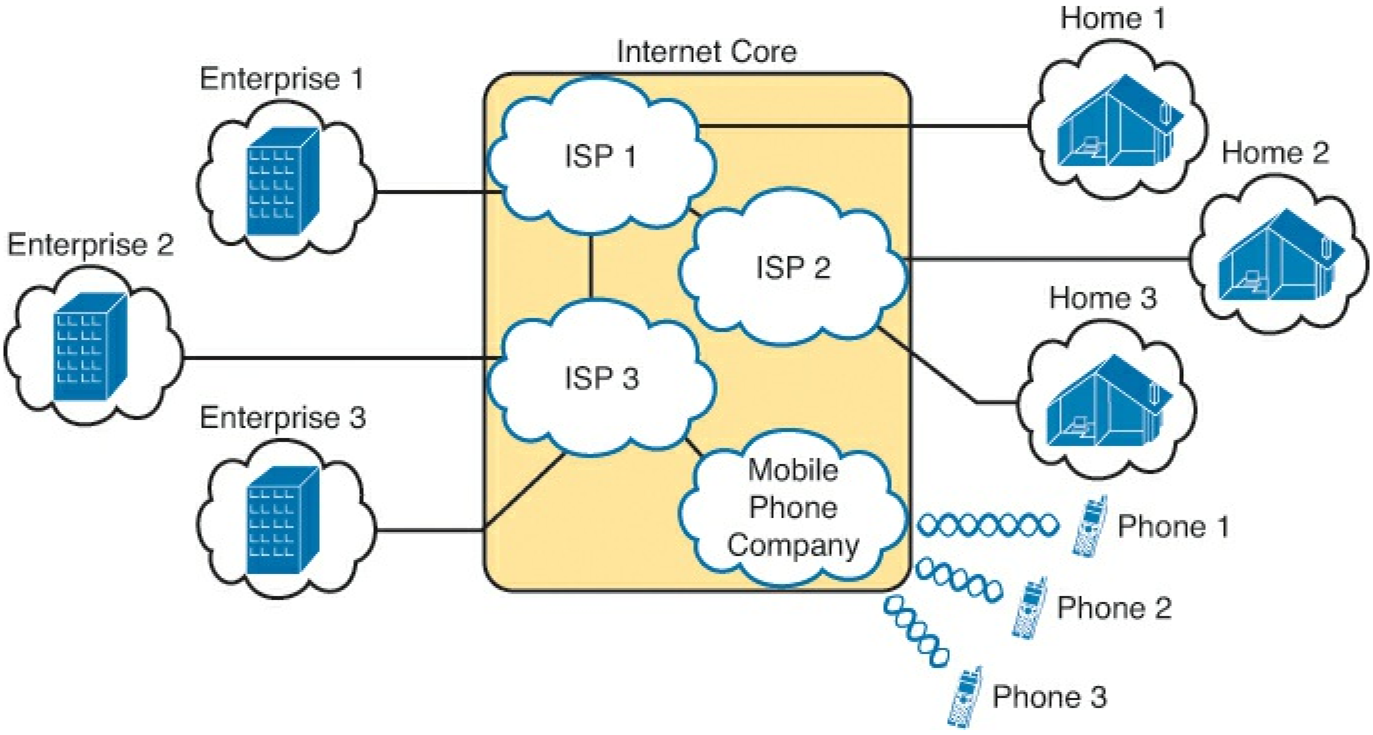

Internet Core
Enterprise 1
Enterprise 2
Enterprise 3
ISP 1
ISP 2
ISP 3
Mobile Phone Company
Home 1
Home 2
Home 3
Phone 1
Phone 2
Phone 3

Figure 3-13. Internet Core with Multiple ISPs and Telcos

Internet Access (WAN) Links

The Internet also happens to use a huge number of WAN links. All of those lines connecting an enterprise or home to one of the ISPs in Figure 3-13 represent some kind of WAN link that uses a cable, while the phones create their WAN link using wireless technology. These links usually go by the name *Internet access link*.

Historically, businesses tend to use one set of WAN technologies as Internet access links, while home-based consumers use others. Businesses often use leased lines, connecting a router at the business to a router at the ISP. The top of Figure 3-14 shows just such an example.

Key Topic

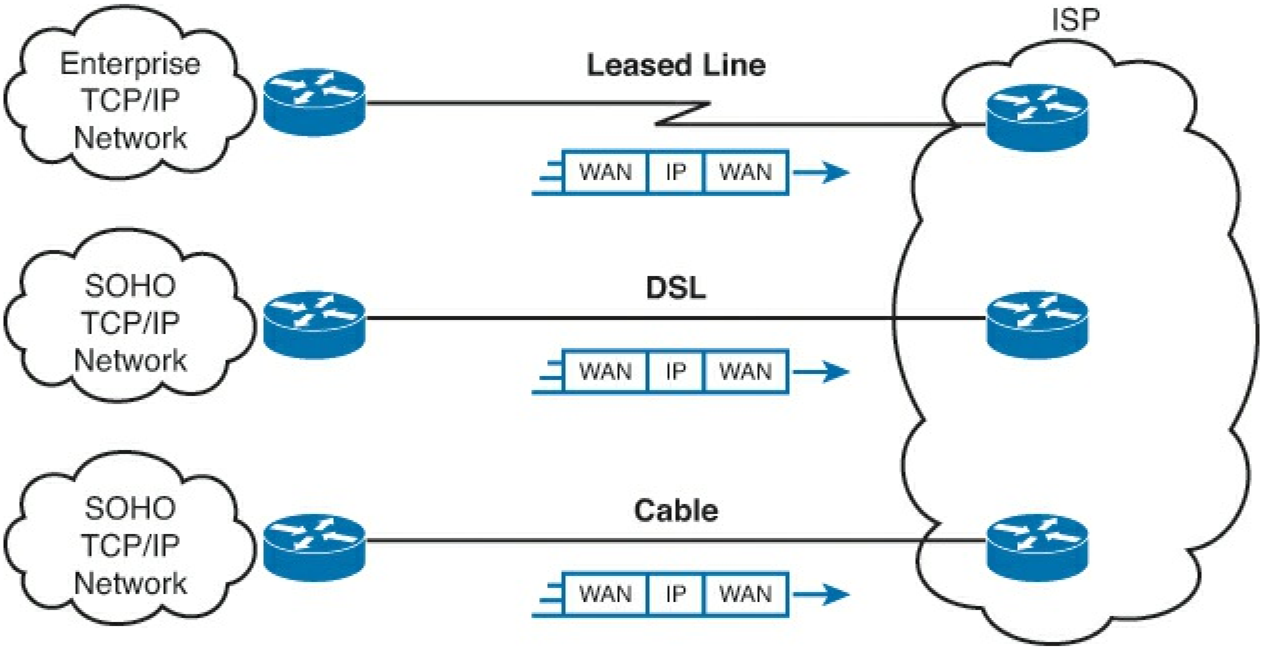


Figure 3-14. Three Examples of Internet Access Links

Consumers often use technologies like DSL and cable for Internet access links. These technologies use cabling that is already installed in most homes, making these services somewhat inexpensive for home users. DSL uses the analog phone lines that are already installed in homes, while cable Internet uses the cable TV (CATV) cable.

> **Note**
>
> While mostly home-based consumers use DSL and cable, there is no restriction against businesses using them as well.

All three of the Internet access technologies in Figure 3-14 happen to use a pair of routers: one at the customer side of the WAN link and one at the ISP side. The routers will continue to think about network layer logic, of sending IP packets to their destination by forwarding the packets to the next router. However, the physical and data link layer details on the WAN link differ as compared to leased lines. The next few pages examine both DSL and cable Internet to show some of those differences.

Digital Subscriber Line

Digital subscriber line (DSL) creates a relatively short (miles long, not tens of miles) high-speed link WAN between a telco customer and an ISP. To do so, it uses the same single-pair telephone line used for a typical home phone line. DSL, as a technology, does not try to replace leased lines, which run between any two sites, for potentially very long distances. DSL instead just provides a short physical link from a home to the telco’s network, allowing access to the Internet..

First, to get an idea about the cabling, think about typical home telephone service in the United States, before adding DSL service. Each home has one phone line that runs from a nearby telco CO to the home. As shown on the left side of Figure 3-15, the telephone wiring splits out and terminates at several wall plates, often with RJ-11 ports that are a slightly skinnier cousin of the RJ-45 connector.

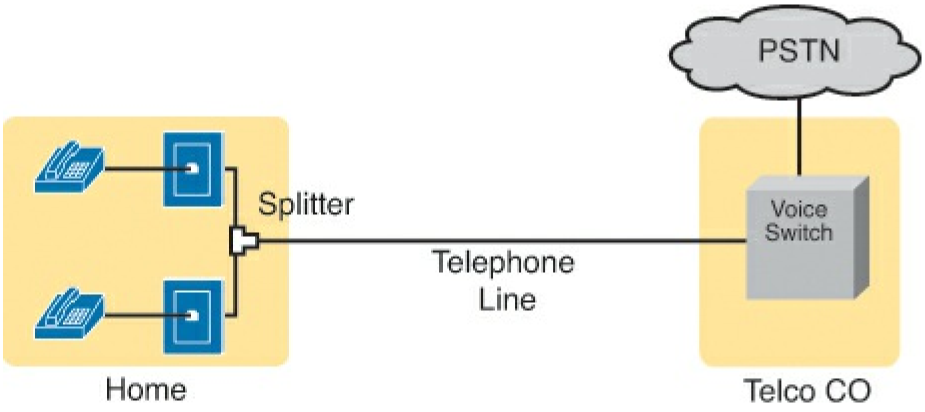


Figure 3-15. Typical Voice Cabling Concepts in the United States

Next, think about the telephone line and the equipment at the CO. Sometime in the past, the telco installed all the telephone lines from its local CO to each neighborhood, apartment, and so on. At the CO, each line connects to a port on a telco switch. This switch supports the ability to set up voice calls, take them down, and forward the voice through the worldwide voice network, called the public switched telephone network, or PSTN.

To add DSL service at the home in Figure 3-15, two changes need to be made. First, you need to add DSL-capable devices at the home. Second, the telco has to add DSL equipment at the CO. Together, the DSL equipment at each side of the local telephone line can send data while still supporting the same voice traffic.

The left side of Figure 3-16 shows the changes. A new *DSL modem* now connects to a spare phone outlet. The DSL modem follows the DSL physical and data link layer standards to send data to/from the telco. The home now has a small LAN, implemented with a consumer-grade router, which often includes an Ethernet switch and possibly a wireless LAN access point.

Key Topic

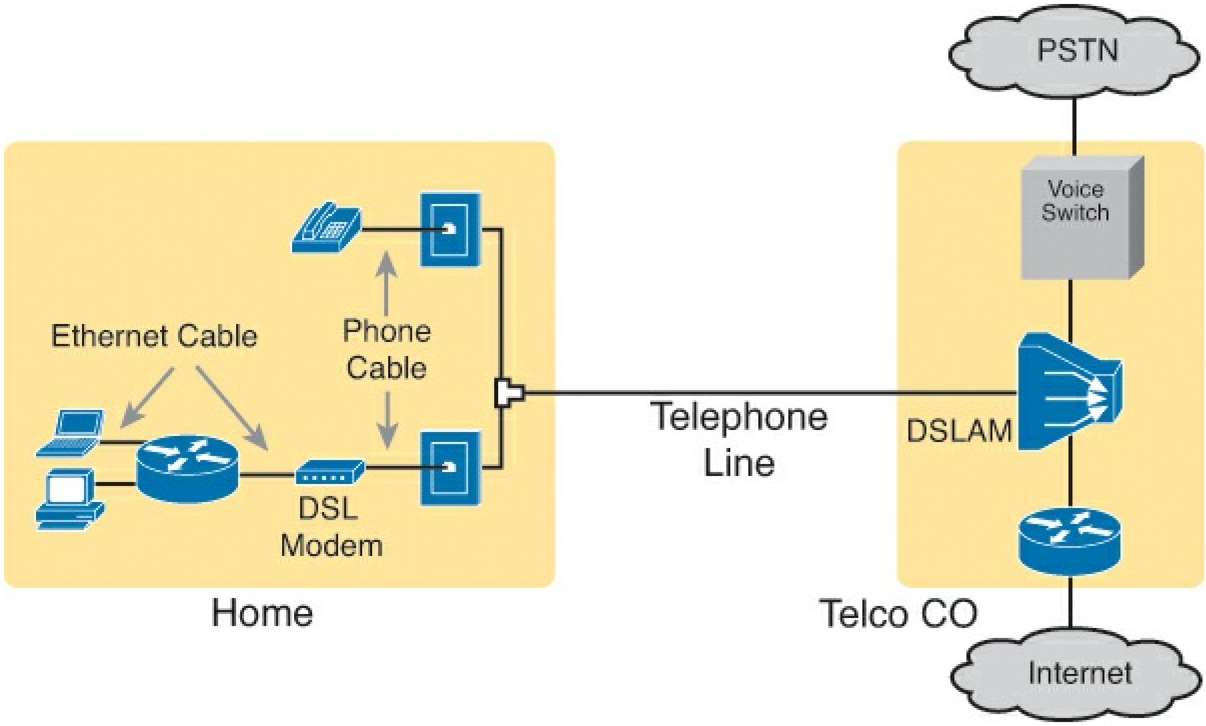


Figure 3-16. Wiring and Devices for a Home DSL Link

The home-based router on the left needs to be able to send data to/from the Internet. To make that happen, the telco CO uses a product called a DSL Access Multiplexer (DSLAM). The DSLAM splits out the data over to the router on the lower right, which completes the connection to the Internet. The DSLAM also splits out the voice signals over to the voice switch on the upper right.

DSL gives telcos a useful high-speed Internet service to offer their customers. Telcos have had other offerings that happen to use the same telephone line for data, but these options ran much slower than DSL. DSL supports asymmetric speeds, meaning that the transmission speed from the ISP toward the home (downstream) is much faster than the transmissions toward the ISP (upstream). Asymmetric speeds work better for consumer Internet access from the home, because clicking a web page sends only a few hundred bytes upstream into the Internet, but can trigger many megabytes of data to be delivered downstream to the home.

Cable Internet

Cable Internet creates an Internet access service which, when viewed generally rather than specifically, has many similarities to DSL. Like DSL, cable Internet takes full advantage of existing cabling, using the existing cable TV (CATV) cable to send data. Like DSL, cable Internet uses asymmetric speeds, sending data faster downstream than upstream, which works better than symmetric speeds for most consumer locations. And like DSL, cable Internet does not attempt to replace long leased lines between any two sites, instead focusing on the short WAN links from a customer to an ISP.

Cable Internet also uses the same basic in-home cabling concepts as does DSL. Figure 3-17 shows a figure based on the earlier DSL Figure 3-16, but with the DSL details replaced with cable Internet details. The telephone line has been replaced with coaxial cable from the CATV company, and the DSL modem has been replaced by a cable modem. Otherwise, the details in the home follow the same overall plan.

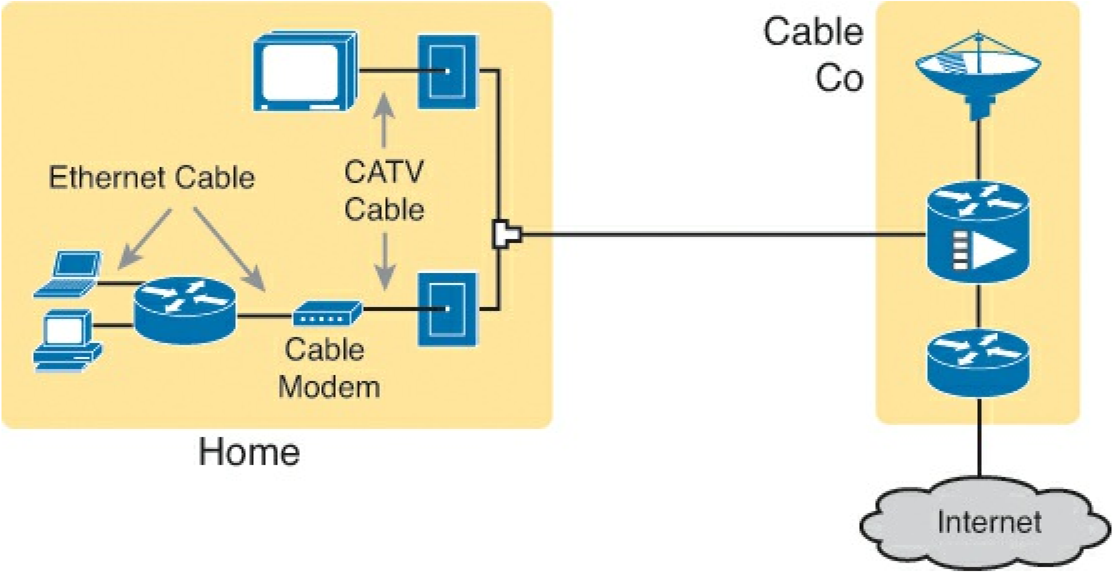


Figure 3-17. Wiring and Devices for a Home Cable Internet Link

On the CATV company side of the cable Internet service, the CATV company has to split out the data and video, as shown on the right side of the figure. Data flows to the lower right, through a router, while video comes in from video dishes for distribution out to the TVs in people's homes.

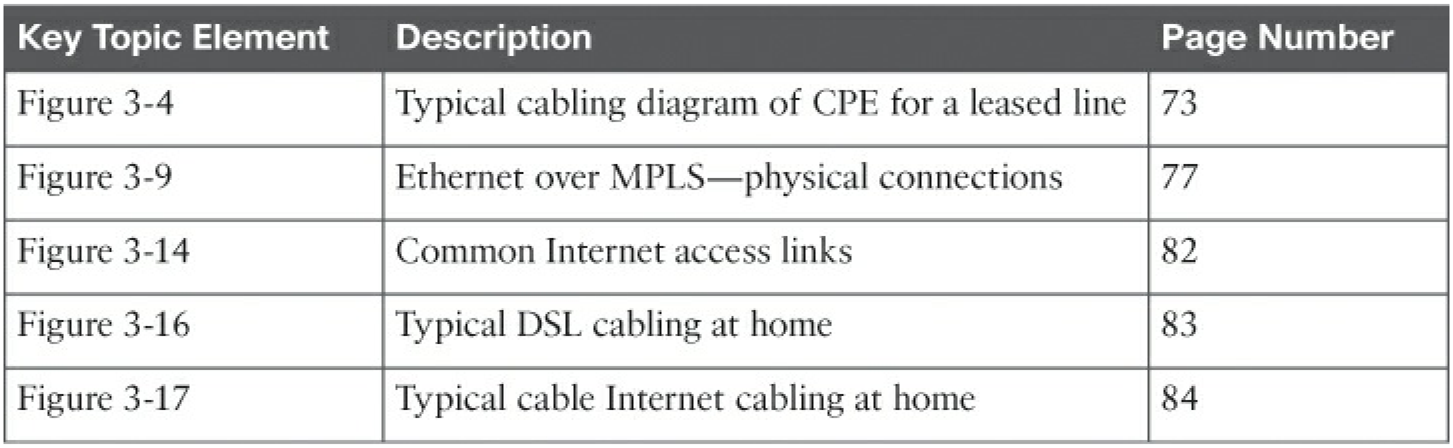
Cable Internet service and DSL directly compete for consumer and small-business Internet access. Generally speaking, while both offer high speeds, cable Internet typically runs at faster speeds than DSL, with DSL providers keeping their prices a little lower to compete. Both support asymmetric speeds, and both provide an "always on" service, in that you can communicate with the Internet without the need to first take some action to start the Internet connection.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 3-4 lists these key topics and where each is discussed.

Table 3-4. Key Topics for Chapter 3



Key Topic Element	Description	Page Number
Figure 3-4	Typical cabling diagram of CPE for a leased line	73
Figure 3-9	Ethernet over MPLS—physical connections	77
Figure 3-14	Common Internet access links	82
Figure 3-16	Typical DSL cabling at home	83
Figure 3-17	Typical cable Internet cabling at home	84

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

leased line
wide-area network (WAN)
telco
serial interface
HDLC
DSL
cable Internet
DSL modem
Ethernet over MPLS

Chapter 4. Fundamentals of IPv4 Addressing and Routing

This chapter covers the following exam topics:

- **Operation of IP Data Networks**
  - Recognize the purpose and functions of various network devices such as Routers, Switches, Bridges and Hubs.
  - Select the components required to meet a given network specification.
  - Predict the data flow between two hosts across a network.
- **IP Routing Technologies**
  - Differentiate methods of routing and routing protocols
    - Static vs. Dynamic

The TCP/IP network layer (Layer 3) defines how to deliver IP packets over the entire trip, from the original device that creates the packet to the device that needs to receive the packet. That process requires cooperation between several different jobs and concepts on a number of devices. This chapter begins with an overview of all these cooperating functions, and then it dives into more detail about each area, as follows:

IP routing: The process of hosts and routers forwarding IP packets (Layer 3 PDUs), while relying on the underlying LANs and WANs to forward the bits.

IP addressing: Addresses used to identify a packet's source and destination host computer. Addressing rules also organize addresses into groups, which greatly assists the routing process.

IP routing protocol: A protocol that aids routers by dynamically learning about the IP address groups so that a router knows where to route IP packets so that they go to the right destination host.

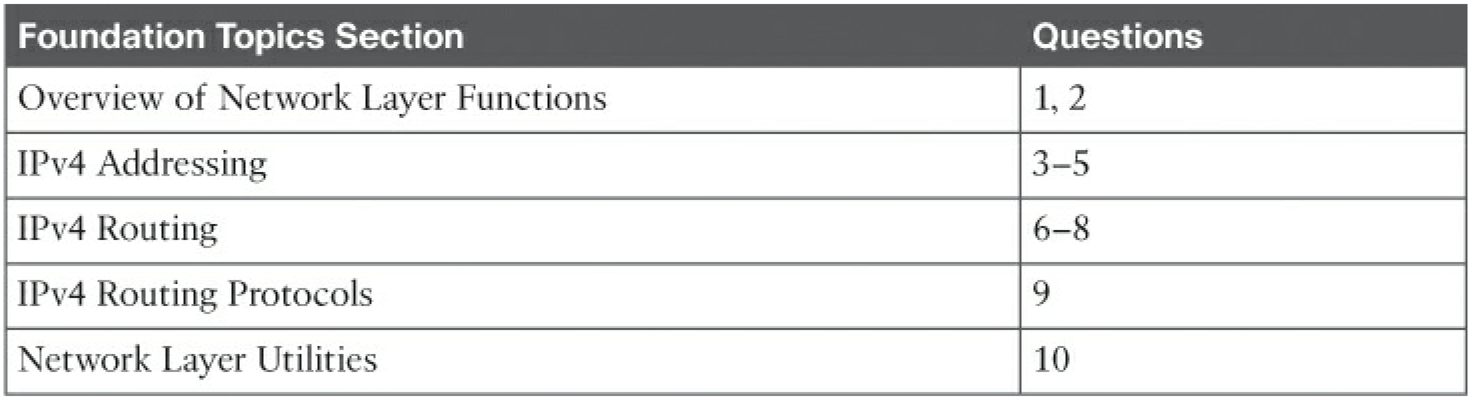
Other utilities: The network layer also relies on other utilities. For TCP/IP, these utilities include Domain Name System (DNS), Address Resolution Protocol (ARP), and ping.

Note that all these functions have variations both for the well-established IP version 4 (IPv4) and for the emerging newer IP version 6 (IPv6). This chapter focuses on IPv4 and the related protocols. Part VII of this book looks at the same kinds of functions for IPv6.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 4-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Overview of Network Layer Functions	1, 2
IPv4 Addressing	3–5
IPv4 Routing	6–8
IPv4 Routing Protocols	9
Network Layer Utilities	10

1. Which of the following are functions of OSI Layer 3 protocols? (Choose two answers.)
   - **a.** Logical addressing
   - **b.** Physical addressing
   - **c.** Path selection
   - **d.** Arbitration
   - **e.** Error recovery
2. Imagine that PC1 needs to send some data to PC2, and PC1 and PC2 are separated by several routers. Both PC1 and PC2 sit on different Ethernet LANs. What are the largest entities (in size) that make it from PC1 to PC2? (Choose two answers.)
   - **a.** Frame
   - **b.** Segment
   - **c.** Packet
   - **d.** L5 PDU

e. L3 PDU

f. L1 PDU

3. Which of the following is a valid Class C IP address that can be assigned to a host?

   a. 1.1.1.1

   b. 200.1.1.1

   c. 128.128.128.128

   d. 224.1.1.1

   e. 223.223.223.255

4. What is the assignable range of values for the first octet for Class A IP networks?

   a. 0 to 127

   b. 0 to 126

   c. 1 to 127

   d. 1 to 126

   e. 128 to 191

   f. 128 to 192

5. PC1 and PC2 are on two different Ethernet LANs that are separated by an IP router. PC1's IP address is 10.1.1.1, and no subnetting is used. Which of the following addresses could be used for PC2? (Choose two answers.)

   a. 10.1.1.2

   b. 10.2.2.2

   c. 10.200.200.1

   d. 9.1.1.1

   e. 225.1.1.1

   f. 1.1.1.1

6. Imagine a network with two routers that are connected with a point-to-point HDLC serial link. Each router has an Ethernet, with PC1 sharing the Ethernet with Router1 and PC2 sharing the Ethernet with Router2. When PC1 sends data to PC2, which of the following is true?

   a. Router1 strips the Ethernet header and trailer off the frame received from PC1, never to be used again.

   b. Router1 encapsulates the Ethernet frame inside an HDLC header and sends the frame to Router2, which extracts the Ethernet frame for forwarding to PC2.

   c. Router1 strips the Ethernet header and trailer off the frame received from PC1, which is exactly re-created by Router2 before forwarding data to PC2.

   d. Router1 removes the Ethernet, IP, and TCP headers and rebuilds the appropriate headers before forwarding the packet to Router2.

7. Which of the following does a router normally use when making a decision about routing TCP/IP packets?

   a. Destination MAC address

   b. Source MAC address

   c. Destination IP address

   d. Source IP address

   e. Destination MAC and IP address

8. Which of the following are true about a LAN-connected TCP/IP host and its IP routing (forwarding) choices? (Choose two answers.)

   a. The host always sends packets to its default gateway.

   b. The host sends packets to its default gateway if the destination IP address is in a different class of IP network than the host.

   c. The host sends packets to its default gateway if the destination IP address is in a different subnet than the host.

   d. The host sends packets to its default gateway if the destination IP address is in the same subnet as the host.

9. Which of the following are functions of a routing protocol? (Choose two answers.)

   a. Advertising known routes to neighboring routers

   b. Learning routes for subnets directly connected to the router

   c. Learning routes, and putting those routes into the routing table, for routes advertised to the router by its neighboring routers

   d. Forwarding IP packets based on a packet's destination IP address

10. A company implements a TCP/IP network, with PC1 sitting on an Ethernet LAN. Which of the following protocols and features requires PC1 to learn information from some other server device?

    a. ARP

    b. ping

    c. DNS

d. None of the other answers are correct

Answers to the "Do I Know This Already?" quiz:

1 A and C **2** C and E **3** B **4** D **5** D and F **6** A **7** C **8** B and C **9** A and C **10** C

Foundation Topics

Overview of Network Layer Functions

While many protocol models have existed over the years, today the TCP/IP model dominates. And at the network layer of TCP/IP, two options exist for the main protocol around which all other network layer functions revolve: IP version 4 (IPv4) and IP version 6 (IPv6). Both IPv4 and IPv6 define the same kinds of network layer functions, but with different details. This chapter introduces these network layer functions for IPv4, leaving the IPv6 details until Part VII of this book.

> **Note**
>
> All references to IP in this chapter refer to the older and more established IPv4.

IP focuses on the job of routing data, in the form of IP packets, from the source host to the destination host. IP does not concern itself with the physical transmission of data, instead relying on the lower TCP/IP layers to do the physical transmission of the data. Instead, IP concerns itself with the logical details, instead of physical details, of delivering data. In particular, the network layer specifies how packets travel end to end over a TCP/IP network, even when the packet crosses many different types of LAN and WAN links.

This first section of the chapter begins a broad discussion of the TCP/IP network layer by looking at IP routing and addressing. The two topics work together, because IP routing relies on the structure and meaning of IP addresses, and IP addressing was designed with IP routing in mind. Following that, this overview section looks at routing protocols, which let routers learn the information they need to know to do routing correctly.

Network Layer Routing (Forwarding) Logic

Routers and end-user computers (called *hosts* in a TCP/IP network) work together to perform IP routing. The host operating system (OS) has TCP/IP software, including the software that implements the network layer. Hosts use that software to choose where to send IP packets, oftentimes to a nearby router. Those routers make choices of where to send the IP packet next. Together, the hosts and routers deliver the IP packet to the correct destination, as seen in the example in Figure 4-1.

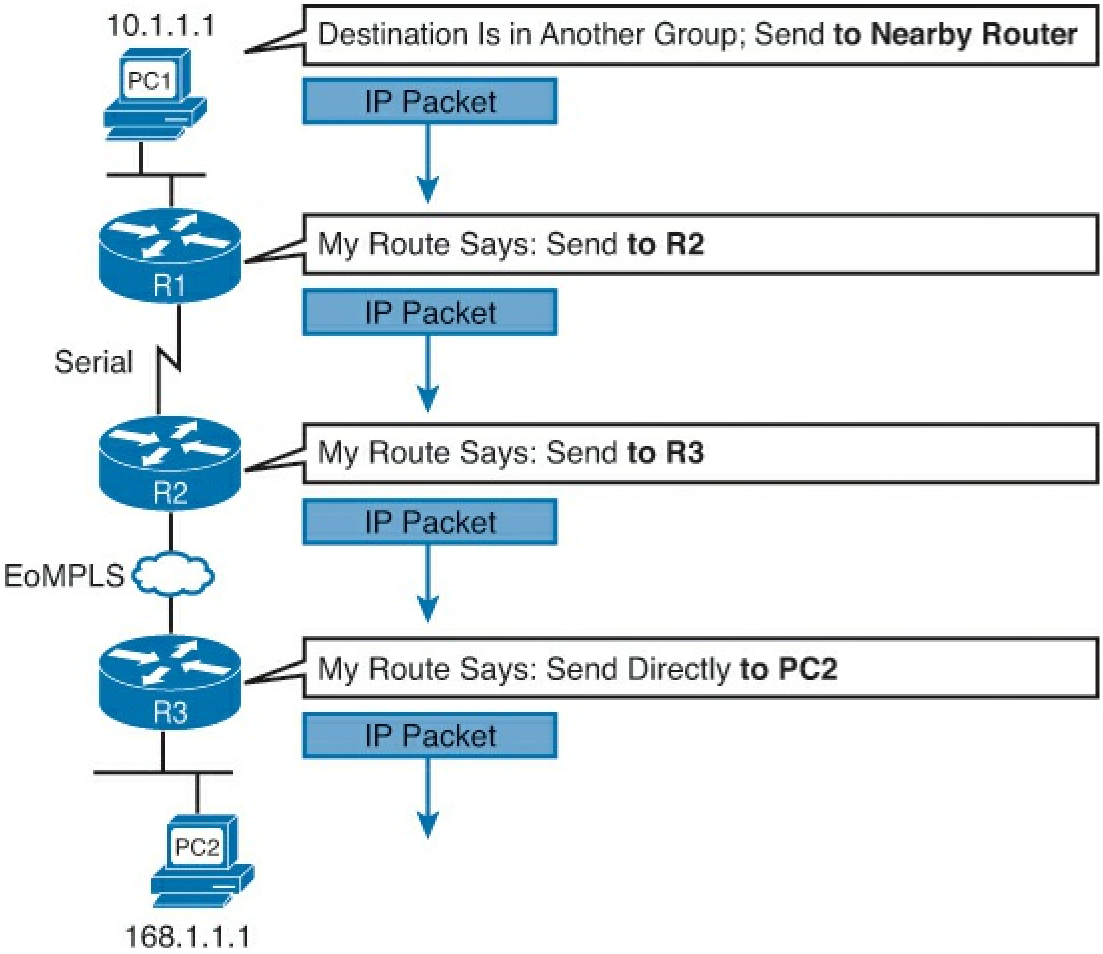

10.1.1.1
PC1
Destination Is in Another Group; Send to Nearby Router
IP Packet
R1
My Route Says: Send to R2
IP Packet
Serial
R2
My Route Says: Send to R3
IP Packet
EoMPLS
R3
My Route Says: Send Directly to PC2
IP Packet
PC2
168.1.1.1

Figure 4-1. Routing Logic: PC1 Sending an IP Packet to PC2

The IP packet, created by PC1, goes from the top of the figure all the way to PC2 at the bottom of the figure. The next few pages discuss the network layer routing logic used by each device along the path.

> **Note**
>
> The term *path selection* is sometimes used to refer to the routing process shown in Figure 4-1. At other times, it refers to routing protocols, specifically how routing protocols select the best route among the competing routes to the same destination.

Host Forwarding Logic: Send the Packet to the Default Router

In this example, PC1 does some basic analysis, and then chooses to send the IP packet to the router so that the router will forward the packet. PC1 analyzes the destination address and realizes that PC2's address (168.1.1.1) is not on the same LAN as PC1. So PC1's logic tells it to send the packet to a device whose job it is to know where to route data: a nearby router, on the same LAN, called PC1's default router.

To send the IP packet to the default router, the sender sends a data link frame across the medium to the nearby router; this frame includes the packet in the data portion of the frame. That frame uses data link layer (Layer 2) addressing in the data link header to ensure that the nearby router receives the frame.

> **Note**
>
> The *default router* is also referred to as the *default gateway*.

R1 and R2's Logic: Routing Data Across the Network

All routers use the same general process to route the packet. Each router keeps an *IP routing table*. This table lists IP address *groupings*, called *IP networks* and *IP subnets*. When a router receives a packet, it compares the packet's destination IP address to the entries in the routing table and makes a match. This matching entry also lists directions that tell the router where to forward the packet next.

In Figure 4-1, R1 would have matched the destination address (168.1.1.1) to a routing table entry, which in turn told R1 to send the packet to R2 next. Similarly, R2 would have matched a routing table entry that told R2 to send the packet, over an Ethernet over MPLS (EoMPLS) link, to R3 next.

The routing concept works a little like driving down the freeway when approaching a big interchange. You look up and see signs for nearby towns, telling you which exits to take to go to each town. Similarly, the router looks at the IP routing table (the equivalent of the road signs) and directs each packet over the correct next LAN or WAN link (the equivalent of a road).

R3's Logic: Delivering Data to the End Destination

The final router in the path, R3, uses almost the same logic as R1 and R2, but with one minor difference. R3 needs to forward the packet directly to PC2, not to some other router. On the surface, that difference seems insignificant. In the next section, when you read about how the network layer uses LANs and WANs, the significance of the difference will become obvious.

How Network Layer Routing Uses LANs and WANs

While the network layer routing logic ignores the physical transmission details, the bits still have to be transmitted. To do that work, the network layer logic in a host or router must hand off the packet to the data link layer protocols, which, in turn, ask the physical layer to actually send the data. And as was described in Chapter 2, "Fundamentals of Ethernet LANs," the data link layer adds the appropriate header and trailer to the packet, creating a frame, before sending the frames over each physical network.

The routing process forwards the network layer packet from end to end through the network, while each data link frame only takes a smaller part of the trip. Each successive data link layer frame moves the packet to the next device that thinks about network layer logic. In short, the network layer thinks about the bigger view of the goal, like "Send this packet to the specified next device...," while the data link layer thinks about the specifics, like "Encapsulate the packet in a data link frame and transmit it." Figure 4-2 points out the key encapsulation logic on each device, using the same examples as shown in Figure 4-1.

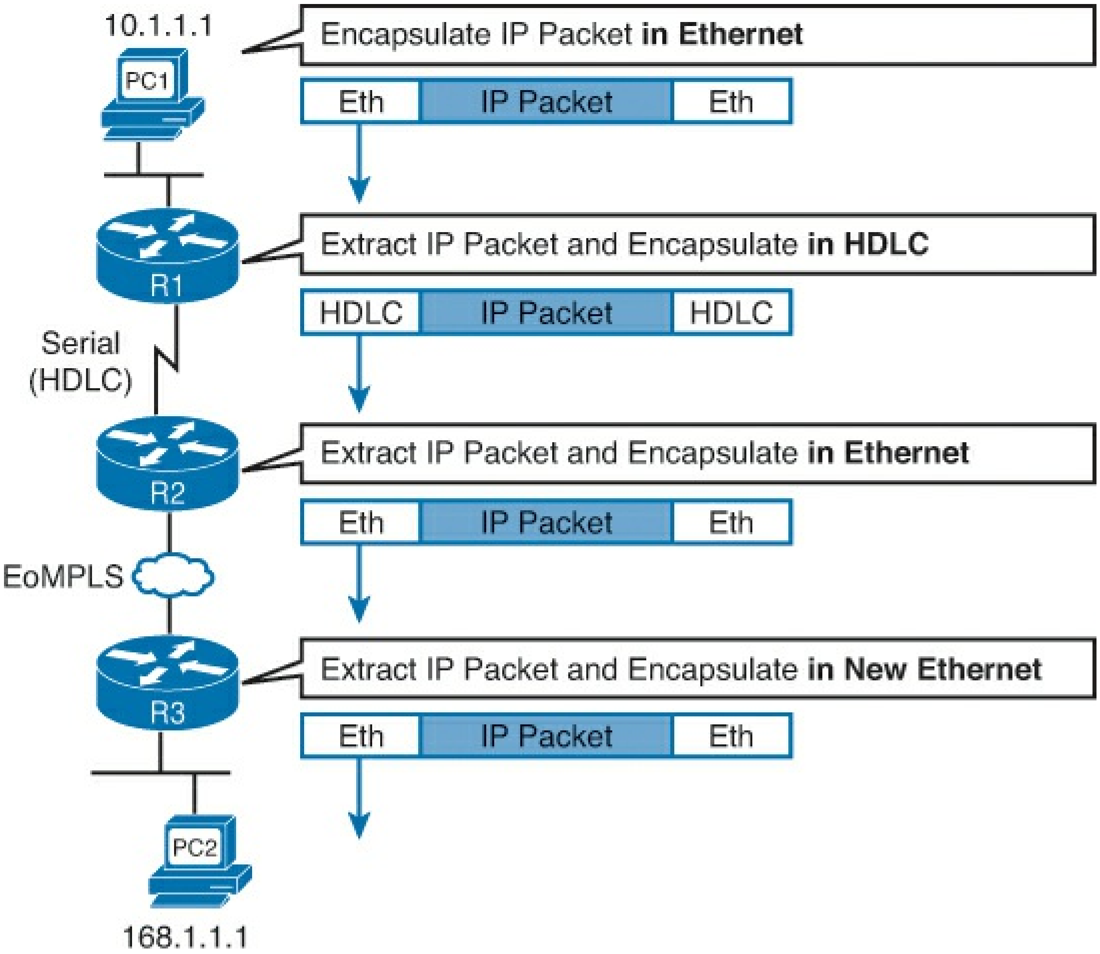

10.1.1.1
PC1
Encapsulate IP Packet **in Ethernet**
Eth
IP Packet
Eth
R1
Extract IP Packet and Encapsulate **in HDLC**
HDLC
IP Packet
HDLC
Serial (HDLC)
R2
Extract IP Packet and Encapsulate **in Ethernet**
Eth
IP Packet
Eth
EoMPLS
R3
Extract IP Packet and Encapsulate **in New Ethernet**
Eth
IP Packet
Eth
PC2
168.1.1.1

Figure 4-2. Network Layer and Data Link Layer Encapsulation

Because the routers build new data link headers and trailers, and because the new headers contain data link addresses, the PCs and routers must have some way to decide what data link addresses to use. An example of how the router determines which data link address to use is the IP Address Resolution Protocol (ARP). *ARP dynamically learns the data link address of an IP host connected to a LAN*. For example, at the last step, at the bottom of Figure 4-2, router R3 would use ARP once to learn PC2's MAC address before sending any packets to PC2.

Routing as covered so far has two main concepts:

- The process of routing forwards Layer 3 packets, also called *Layer 3 protocol data units (L3 PDU)*, based on the destination Layer 3 address in the packet.
- The routing process uses the data link layer to encapsulate the Layer 3 packets into Layer 2 frames for transmission across each successive data link.

IP Addressing and How Addressing Helps IP Routing

IP defines network layer addresses that identify any host or router interface that connects to a TCP/IP network. The idea basically works like a postal address: Any interface that expects to receive IP packets needs an IP address, just like you need a postal address before receiving mail from the postal service.

TCP/IP groups IP addresses together so that IP addresses used on the same physical network are part of the same group. IP calls these address groups an *IP network* or an *IP subnet*. Using that same postal service analogy, each IP network and IP subnet works like a postal code (or in the United States, a ZIP code). All nearby postal addresses are in the same postal code (ZIP code), while all nearby IP addresses must be in the same IP network or IP subnet.

> **Note**
>
> IP defines the word *network* to mean a very specific concept. To avoid confusion when writing about IP addressing, this book (and others) often avoid using the term *network* for other uses. In particular, this book uses the term *internetwork* to refer more generally to a network made up of routers, switches, cables, and other equipment.

IP defines specific rules about which IP address should be in the same IP network or IP subnet. Numerically, the addresses in the same group have the same value in the first part of the addresses. For example, Figures 4-1 and 4-2 could have used the following conventions:

- Hosts on the top Ethernet: Addresses start with 10
- Hosts on the R1-R2 serial link: Addresses start with 168.10
- Hosts on the R2-R3 EoMPLS link: Addresses start with 168.11
- Hosts on the bottom Ethernet: Addresses start with 168.1

It’s similar to the USPS ZIP code system and how it requires local governments to assign addresses to new buildings. It would be ridiculous to have two houses, next door to each other, whose addresses had different ZIP codes. Similarly, it would be silly to have people who live on opposite sides of the country to have addresses with the same ZIP code.

Similarly, to make routing more efficient, network layer protocols group addresses, both by their location and by the actual address values. A router can list one routing table entry for each IP network or subnet, instead of one entry for every single IP address.

The routing process also makes use of the IPv4 header, as shown in Figure 4-3. The header lists a 32-bit source IP address, as well as a 32-bit destination IP address. The header of course has other fields, a few of which matter for other discussions in this book. The book will refer back to this figure as needed, but otherwise, be aware of the 20-byte IP header and the existence of the source and destination IP address fields.

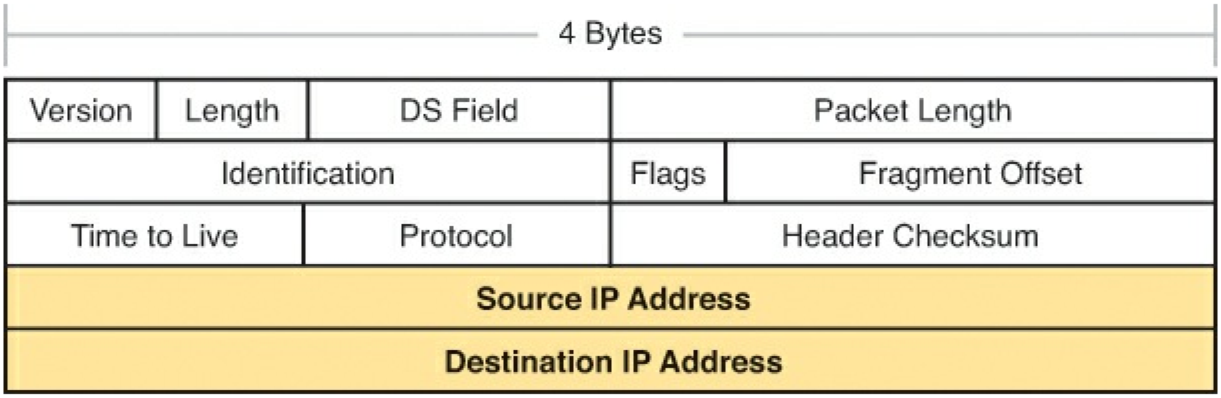


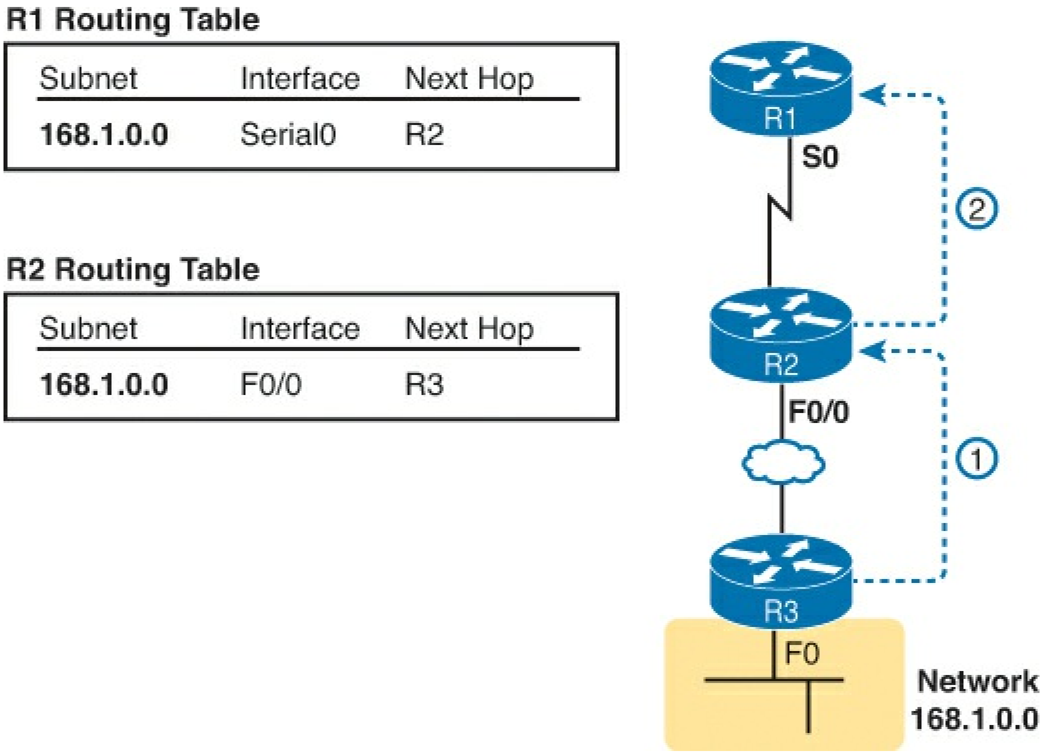
Figure 4-3. IPv4 Header, Organized as Four Bytes Wide for a Total of 20 Bytes

Routing Protocols

For routing logic to work on both hosts and routers, each needs to know something about the TCP/IP internetwork. Hosts need to know the IP address of their default router so that hosts can send packets to remote destinations. Routers, however, need to know routes so that routers know how to forward packets to each and every IP network and IP subnet.

Although a network engineer could configure (type) all the required routes, on every router, most network engineers instead simply enable a routing protocol on all routers. If you enable the same routing protocol on all the routers in a TCP/IP internetwork, with the correct settings, the routers will send routing protocol messages to each other. As a result, all the routers will learn routes for all the IP networks and subnets in the TCP/IP internetwork.

Figure 4-4 shows an example, using the same diagram as in Figures 4-1 and 4-2. In this case, IP network 168.1.0.0, which consists of all addresses that begin with 168.1, sits on the Ethernet at the bottom of the figure. R3, knowing this fact, sends a routing protocol message to R2 (Step 1). R2 learns a route for network 168.1.0.0 as a result, as shown on the left. At Step 2, R2 turns around and sends a routing protocol message to R1 so that R1 now has a route for that same IP network (168.1.0.0).



R1 Routing Table

Subnet	Interface	Next Hop
168.1.0.0	Serial0	R2

R2 Routing Table

Subnet	Interface	Next Hop
168.1.0.0	F0/0	R3

Figure 4-4. Example of How Routing Protocols Advertise About Networks and Subnets

This concludes the overview of how the TCP/IP network layer works. The rest of this chapter reexamines the key components in more depth.

IPv4 Addressing

IPv4 addressing is absolutely the most important topic for the CCENT and CCNA exams. By the time you have finished reading this book, you should be comfortable and confident in your understanding of IP addresses, their formats, the grouping concepts, how to subdivide groups into subnets, how to interpret the documentation for existing networks' IP addressing, and so on. Simply put, you had better know addressing and subnetting!

This section introduces IP addressing and subnetting and also covers the concepts behind the structure of an IP address, including how it relates to IP routing. In Parts III and V of this book, you will read more about the concepts and math behind IPv4 addressing and subnetting.

Rules for IP Addresses

If a device wants to communicate using TCP/IP, it needs an IP address. When the device has an IP address and the appropriate software and hardware, it can send and receive IP packets. Any device that has at least one interface with an IP address can send and receive IP packets and is called an *IP host*.

IP addresses consist of a 32-bit number, usually written in *dotted-decimal notation (DDN)*. The "decimal" part of the term comes from the fact that each byte (8 bits) of the 32-bit IP address is shown as its decimal equivalent. The four resulting decimal numbers are written in sequence, with "dots," or decimal points, separating the numbers—hence the name *dotted-decimal*. For example, 168.1.1.1 is an IP address written in dotted-decimal form; the actual binary version is 10101000 00000001 00000001 00000001. (You almost never need to write down the binary version, but you can use the conversion chart in Appendix A to easily convert from DDN to binary or vice versa.

Each DDN has four decimal *octets*, separated by periods. The term *octet* is just a vendor-neutral term for *byte*. Because each octet represents an 8-bit binary number, the range of decimal numbers in each octet is between 0 and 255, inclusive. For example, the IP address of 168.1.1.1 has a first octet of 168, the second octet of 1, and so on.

Finally, note that each network interface uses a unique IP address. Most people tend to think that their computer has an IP address, but actually their computer's network card has an IP address. For example, if your laptop has both an Ethernet network interface card (NIC) and a wireless NIC, with both working at the same time, both will have an IP address. Similarly, routers, which typically have many network interfaces that forward IP packets, have an IP address for each interface.

Rules for Grouping IP Addresses

The original specifications for TCP/IP grouped IP addresses into sets of consecutive addresses called *IP networks*. The addresses in a single IP network have the same numeric value in the first part of all addresses in the network. Figure 4-5 shows a simple internetwork that has three separate IP networks.

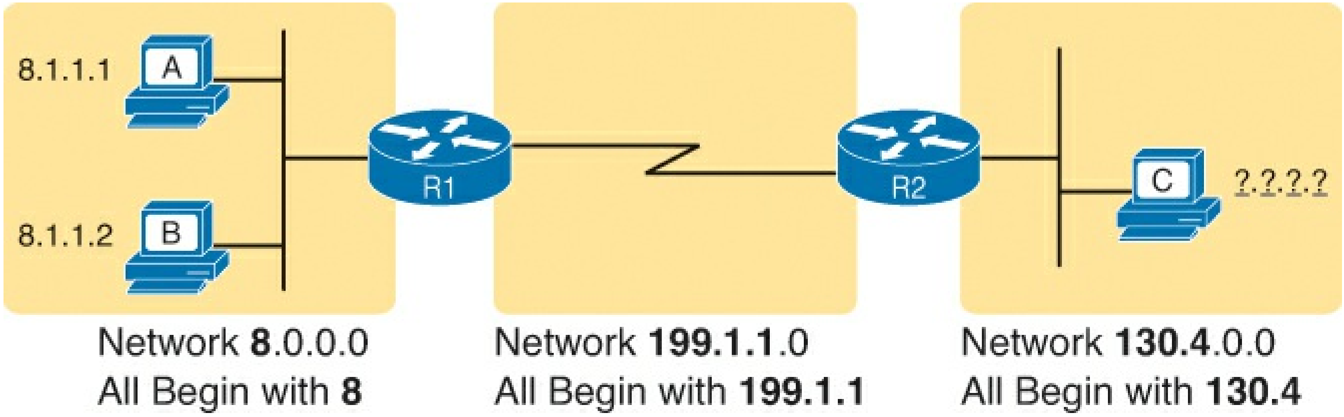


Figure 4-5. Sample TCP/IP Internetwork Using IPv4 Network Numbers

The figure lists a network identifier (network ID) for each network, as well as a text description of the DDN values in each network. For example, the hosts in the Ethernet LAN on the far left use IP addresses that begin with a first octet of 8; the network ID happens to be 8.0.0.0. As another example, the serial link between R1 and R2 consists of only two interfaces—a serial interface on each router—and uses an IP address that begins with the three octets 199.1.1.

Figure 4-5 also provides a good figure with which to discuss two important facts about how IPv4 groups IP addresses:

Key Topic

- All IP addresses in the same group must not be separated from each other by a router.
- IP addresses separated from each other by a router must be in different groups.

Take the first of the two rules, and look at hosts A and B on the left. Hosts A and B are in the same IP network and have IP addresses that begin with 8. Per the first rule, hosts A and B cannot be separated from each other by a router (and they are indeed not separated from each other by a router).

Next, take the second of the two rules and add host C to the discussion. Host C is separated from host A by at least one router, so host C cannot be in the same IP network as host A. Host C's address cannot begin with 8.

> **Note**
>
> This example assumes the use of IP networks only, and no subnets, simply because the discussion has not yet dealt with the details of subnetting.

As mentioned earlier in this chapter, IP address grouping behaves similarly to ZIP codes. Everyone in my ZIP code lives in a little town in Ohio. If some addresses in my ZIP code were in California, some mail might be delivered to the wrong local post office, because the postal service delivers the letters based on the postal (ZIP) codes. The post system relies on all addresses in one postal code being near to each other.

Likewise, IP routing relies on all addresses in one IP network or IP subnet to be in the same location, specifically on a single instance of a LAN or WAN data link. Otherwise, the routers might deliver IP packets to the wrong locations.

For any TCP/IP internetwork, each LAN and WAN link will use either an IP network or an IP subnet. Next, this chapter looks more closely at the concepts behind IP networks, followed by IP subnets.

Class A, B, and C IP Networks

The IPv4 address space includes all possible combinations of numbers for a 32-bit IPv4 address. Literally 2^{32} different values exist with a 32-bit number, for more than 4 billion different numbers. With DDN values, these numbers include all combinations of the values 0 through 255 in all four octets: 0.0.0.0, 0.0.0.1, 0.0.0.2, and all the way up to 255.255.255.255.

IP standards first subdivide the entire address space into classes, as identified by the value of the first octet. Class A gets roughly half of the IPv4 address space, with all DDN numbers that begin with 1–126, as shown in Figure 4-6. Class B gets one-fourth of the address space, with all DDN numbers that begin with 128–191 inclusive, while Class C gets one-eighth of the address space, with all numbers that begin with 192–223.

Key Topic

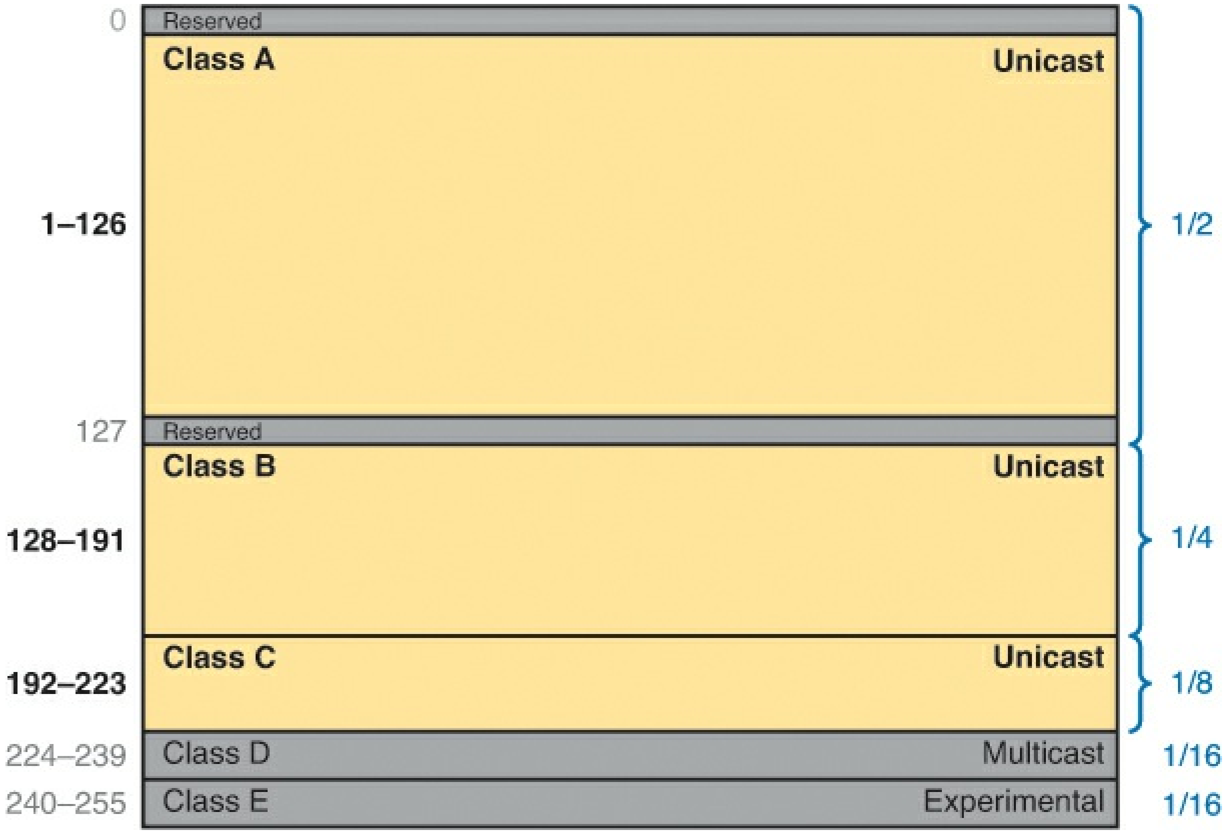

0
Reserved
Class A
Unicast
1–126
1/2
127
Reserved
Class B
Unicast
128–191
1/4
Class C
Unicast
192–223
1/8
224–239
Class D
Multicast
1/16
240–255
Class E
Experimental
1/16

Figure 4-6. Size of Network and Host Parts of Class A, B, and C Addresses

Figure 4-6 also notes the purpose for the five address classes. Classes A, B, and C define unicast IP addresses, meaning that the address identifies a single host interface. Class D defines multicast addresses, used to send one packet to multiple hosts, while Class E defines experimental addresses.

IPv4 standards also subdivide the Class A, B, and C unicast classes into predefined IP networks. Each IP network makes up a subset of the DDN values inside the class.

IPv4 uses three classes of unicast addresses so that the IP networks in each class can be different sizes, and therefore meet different needs. Class A networks each support a very large number of IP addresses (over 16 million host addresses per IP network). However, because each Class A network is so large, Class A holds only 126 Class A networks. Class B defines IP networks that have 65,534 addresses per network, but with space for over 16,000 such networks. Class C defines much smaller IP networks, with 254 addresses each, as shown in Figure 4-7.

Key Topic

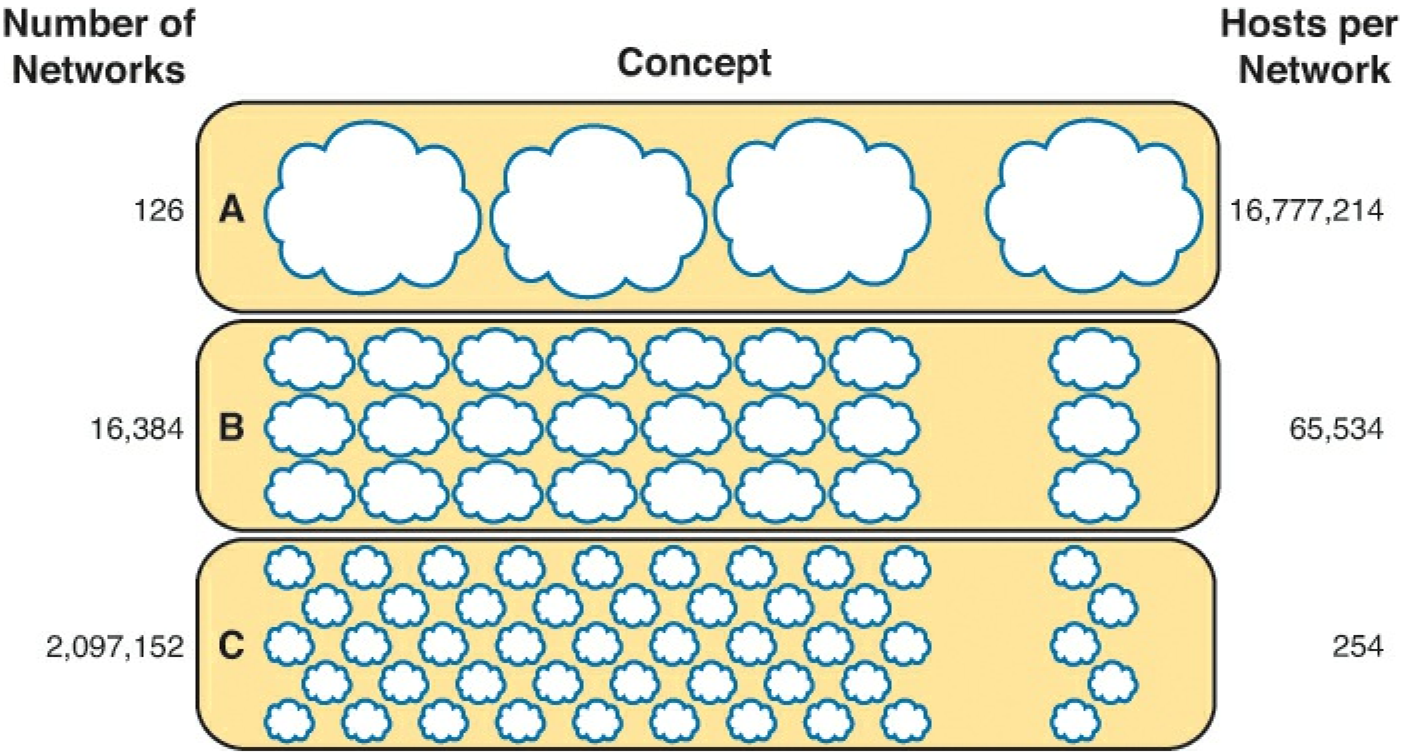


Figure 4-7. Size of Network and Host Parts of Class A, B, and C Addresses

Figure 4-7 shows a visual perspective, as well as the literal numbers, for all the Class A, B, and C IPv4 networks in the entire world. The figure shows clouds for IP networks. It of course does not show one cloud for every possible network, but shows the general idea, with a small number of large clouds for Class A and a large number of small clouds for Class C.

The Actual Class A, B, and C IP Networks

Figure 4-7 shows the number of Class A, B, and C IP networks in the entire world. Eventually, you need to actually pick and use some of these IP networks to build a working TCP/IP internetwork, so you need to be able to answer the question: What are the specific IP networks?

First, you must be able to identify each network briefly using a *network identifier* (network ID). The network ID is just one reserved DDN value per network that identifies the IP network. (The network ID cannot be used by a host as an IP address.) For example, Table 4-2 shows the network IDs that match the earlier Figure 4-5.

Table 4-2. Network IDs Used in Figure 4-5

Concept	Class	Network ID
All addresses that begin with 8	A	8.0.0.0
All addresses that begin with 130.4	B	130.4.0.0
All addresses that begin with 199.1.1	C	199.1.1.0

Note

Many people use the term *network ID*, but others use the terms *network number* and *network address*. Be ready to use all three terms.

So, what are the actual Class A, B, and C IP networks, and what are their network IDs? First, consider the Class A networks. Per Figure 4-7, only 126 Class A networks exist. As it turns out, they consist of all addresses that begin with 1, all addresses that begin with 2, all addresses that begin with 3, and so on, up through the 126th such network of "all addresses that begin with 126." Table 4-3 lists a few of these networks.

Table 4-3. Sampling of IPv4 Class A Networks

Concept	Class	Network ID
All addresses that begin with 8	A	8.0.0.0
All addresses that begin with 13	A	13.0.0.0
All addresses that begin with 24	A	24.0.0.0
All addresses that begin with 125	A	125.0.0.0
All addresses that begin with 126	A	126.0.0.0

Class B networks have a first octet value between 128 and 191, inclusive, but in a single Class B network, the addresses have the same value in the first two octets. For example, Figure 4-5 uses Class B network 130.4.0.0. The DDN value 130.4.0.0 must be in Class B, because the first octet is between 128 and 191, inclusive. However, the first two octets define the addresses in a single Class B network. Table 4-4 lists some sample IPv4 Class B networks.

Table 4-4. Sampling of IPv4 Class B Networks

Concept	Class	Network ID
All addresses that begin with 128.1	B	128.1.0.0
All addresses that begin with 172.20	B	172.20.0.0
All addresses that begin with 191.191	B	191.191.0.0
All addresses that begin with 150.1	B	150.1.0.0

Class C networks can also be easily identified, with a first octet value between 192 and 223, inclusive. With Class C networks and addresses, the first three octets define the group, with addresses in one Class C network having the same value in the first three octets. Table 4-5 shows some samples.

Table 4-5. Sampling of IPv4 Class C Networks

Concept	Class	Network ID
All addresses that begin with 199.1.1	C	199.1.1.0
All addresses that begin with 200.1.200	C	200.1.200.0
All addresses that begin with 223.1.10	C	223.1.10.0
All addresses that begin with 209.209.1	C	209.209.1.0

Listing all the Class A, B, and C networks would of course take too much space. For study review, Table 4-6 summarizes the first octet values that identify the class and summarizes the range of Class A, B, and C network numbers available in the entire IPv4 address space.

Key Topic

Table 4-6. All Possible Valid Network Numbers

Class	First Octet Range	Valid Network Numbers
A	1 to 126	1.0.0.0 to 126.0.0.0
B	128 to 191	128.0.0.0 to 191.255.0.0
C	192 to 223	192.0.0.0 to 223.255.255.0

Note

The term *classful IP network* refers to any Class A, B, or C network, because it is defined by Class A, B, and C rules.

IP Subnetting

Subnetting is one of the most important topics on the exams related to the CCENT and CCNA certifications. You need to know how subnetting works and how to "do the math" to figure out issues when subnetting is an use, both in real life and on the exam. Parts III and V of this book cover the details of subnetting concepts, motivation, and math, but you should have a basic understanding of the concepts before covering the topics between here and Part III.

Subnetting defines methods of further subdividing the IPv4 address space into groups that are smaller than a single IP network. IP subnetting defines a flexible way for anyone to take a single Class A, B, or C IP network and further subdivide it into even smaller groups of consecutive IP addresses. In fact, the name *subnet* is just shorthand for *subdivided network*. Then, in each location where you used to use an entire Class A, B, or C network, you can use a smaller subnet, wasting fewer IP addresses.

To make it clear how an internetwork can use both classful IPv4 networks as well as subnets of classful IPv4 networks, the next two figures show the same internetwork, one with classful networks only and one with subnets only. Figure 4-8 shows the first such example, which uses five Class B networks, with no subnetting.

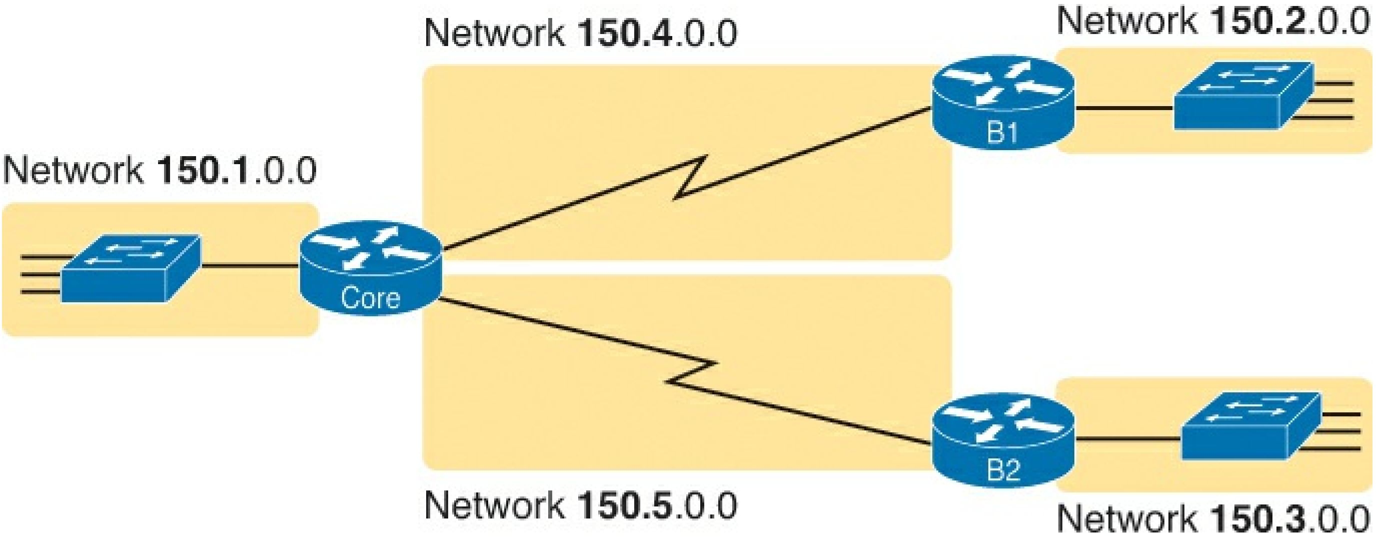


Figure 4-8. Example That Uses Five Class B Networks

The design in Figure 4-8 requires five groups of IP addresses, each of which is a Class B network in this example. Specifically, the three LANs each use a single Class B network, and the two serial links each use a Class B network.

Figure 4-8 wastes many IP addresses, because each Class B network has $2^{16} - 2$ host addresses—far more than you will ever need for each LAN and WAN link. For example, the Ethernet on the left uses an entire Class B network, which supports 65,534 IP addresses that begin with 150.1. However, a single LAN seldom grows past a few hundred devices, so many of the IP addresses in Class B network 150.1.0.0 would be wasted. Even more waste occurs on the point-to-point serial links, which only need two IP addresses.

Figure 4-9 illustrates a more common design today, one that uses basic subnetting. As in the previous figure, this figure needs five groups of addresses. However, in this case, the figure uses five subnets of Class B network 150.9.0.0.

Key Topic

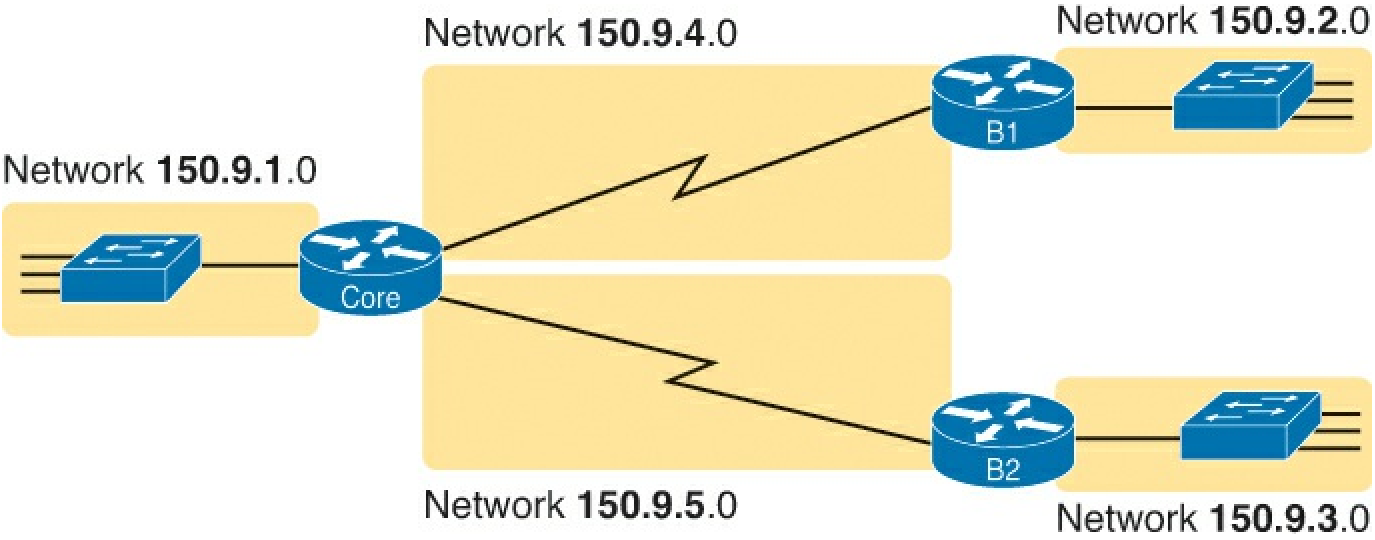


Figure 4-9. Using Subnets for the Same Design as the Previous Figure

Subnetting allows the network engineer for the TCP/IP internetwork to choose to use a longer part of the addresses that must have the same value. Subnetting allows quite a bit of flexibility, but Figure 4-9 shows one of the simplest forms of subnetting. In this case, each subnet includes the addresses that begin with the same value in the first three octets, as follows:

- One group of the 254 addresses that begin with 150.9.1
- One group of the 254 addresses that begin with 150.9.2
- One group of the 254 addresses that begin with 150.9.3
- One group of the 254 addresses that begin with 150.9.4
- One group of the 254 addresses that begin with 150.9.5

As a result of using subnetting, the network engineer has saved many IP addresses. First, only a small part of Class B network 150.9.0.0 has been used so far. Each subnet has 254 addresses, which should be plenty of addresses for each LAN, and more than enough for the WAN links.

> **Note**
>
> All chapters of Parts III and V of this book explain the details of IP addressing, including the methods to choose an IP network and subnet it into smaller subnets.

In summary, you now know some of the details of IP addressing, with a focus on how it relates to routing. Each host and router interface will have an IP address. However, the IP addresses will not be randomly chosen, but will instead be grouped together to aid the routing process. The groups of addresses can be an entire Class A, B, or C network number or it can be a subnet.

IPv4 Routing

In the first section of this chapter ("Overview of Network Layer Functions"), you read about the basics of IPv4 routing using a network with three routers and two PCs. Armed with more knowledge of IP addressing, you now can take a closer look at the process of routing IP. This section begins with the simple two-part routing logic on the originating host, and then moves on to discuss how routers choose where to route or forward packets to the final destination.

IPv4 Host Routing

Hosts actually use some simple routing logic when choosing where to send a packet. If you assume that the design uses subnets (which is typical), this two-step logic is as follows:

Key Topic

Step 1. If the destination IP address is in the same IP subnet as I am, send the packet directly to that destination host.

Step 2. Otherwise, send the packet to my *default gateway*, also known as a *default router*. (This router has an interface on the same subnet as the host.)

For example, consider Figure 4-10 and focus on the Ethernet LAN on the left. When PC1 sends an IP packet to PC11 (150.9.1.11), PC1 first considers some match related to subnetting. PC1 concludes that PC11's IP address is in the same subnet as PC1, so PC1 ignores its default router (Core, 150.9.1.1), sending the packet directly to PC11, as shown in Step 1 of the figure.

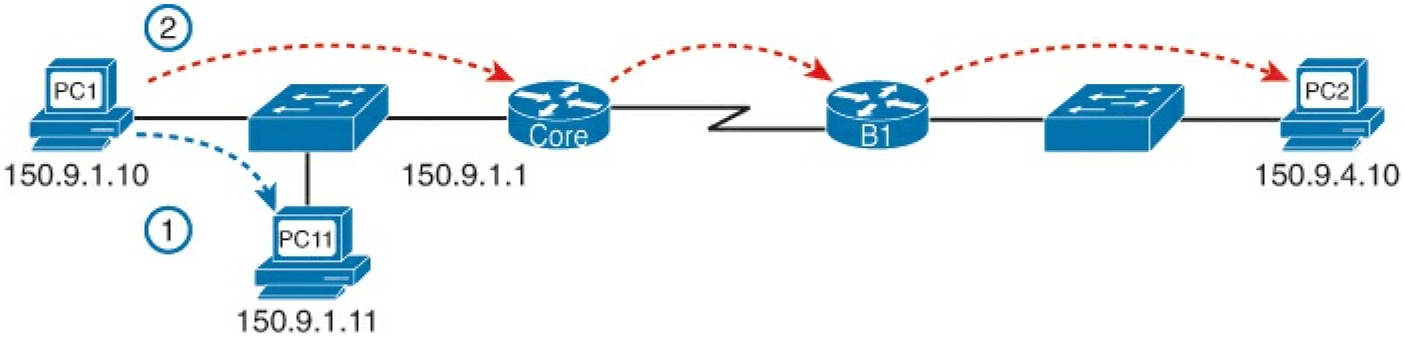


Figure 4-10. Host Routing: Forwarding to a Host on the Same Subnet

Alternatively, when PC1 sends a packet to PC2 (150.9.4.10), PC1 does the same kind of subnetting math, and realizes that PC2 is not on the same subnet as PC1. So, PC1 forwards the packet (Step 2) to its default gateway, 150.9.1.1, which then routes the packet to PC2.

Router Forwarding Decisions and the IP Routing Table

Earlier in this chapter, Figure 4-1 shows the network layer concepts of routing, while Figure 4-2 shows the data link encapsulation logic related to routing. This next topic dives a little deeper into that same process, using an example with three routers forwarding (routing) one packet. But before looking at the example, the text first summarizes how a router thinks about forwarding a packet.

A Summary of Router Forwarding Logic

First, when a router receives a data link frame addressed to that router's data link address, the router needs to think about processing the contents of the frame. When such a frame arrives, the router uses the following logic on the data link frame:

Key Topic

Step 1. Use the data link Frame Check Sequence (FCS) field to ensure that the frame had no errors; if errors occurred, discard the frame.

Step 2. Assuming that the frame was not discarded at Step 1, discard the old data link header and trailer, leaving the IP packet.

Step 3. Compare the IP packet's destination IP address to the routing table, and find the route that best matches the destination address. This route identifies the outgoing interface of the router, and possibly the next-hop router IP address.

Step 4. Encapsulate the IP packet inside a new data link header and trailer, appropriate for the outgoing interface, and forward the frame.

With these steps, each router forwards the packet to the next location, inside a data link frame. With each router repeating this process, the packet reaches its final destination.

While the router does all the steps in the list, Step 3 is the main routing or forwarding step. The packet has a destination IP address in the header, whereas the routing table lists slightly different numbers, typically a list of networks and subnets. To match a routing table entry, the router thinks like this:

> Network numbers and subnet numbers represent a group of addresses that begin with the same prefix. Think about those numbers as groups of addresses. In which of the groups does this packet's destination address reside?

The next example shows specific examples of matching the routing table.

A Detailed Routing Example

The routing example uses Figure 4-11. In this example, all routers happen to use the Open Shortest Path First (OSPF) routing protocol, and all routers know routes for all subnets. In particular, PC2, at the bottom, sits in subnet 150.150.4.0, which consists of all addresses that begin with 150.150.4. In the example, PC1 sends an IP packet to 150.150.4.10, PC2's IP address.

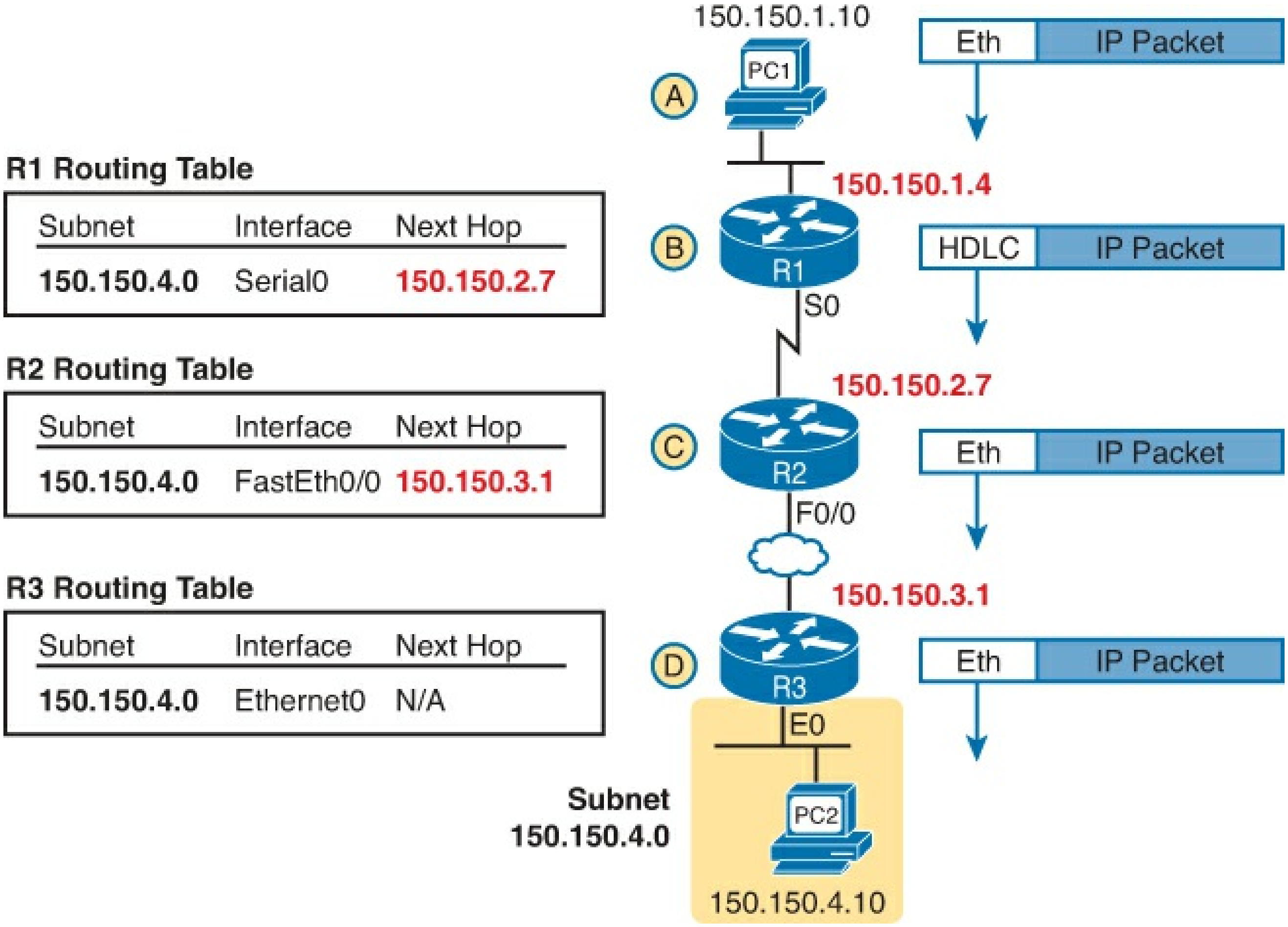

150.150.1.10
PC1
A
Eth
IP Packet
R1 Routing Table
Subnet
Interface
Next Hop
150.150.4.0
Serial0
150.150.2.7
150.150.1.4
B
R1
HDLC
IP Packet
S0
R2 Routing Table
Subnet
Interface
Next Hop
150.150.4.0
FastEth0/0
150.150.3.1
150.150.2.7
C
R2
Eth
IP Packet
F0/0
R3 Routing Table
Subnet
Interface
Next Hop
150.150.4.0
Ethernet0
N/A
150.150.3.1
D
R3
Eth
IP Packet
E0
Subnet
150.150.4.0
PC2
150.150.4.10

Figure 4-11. Simple Routing Example, with IP Subnets

Note

Note that the routers all know in this case that "subnet 150.150.4.0" means "all addresses that begin with 150.150.4."

The following list explains the forwarding logic at each step in the figure. (Note that the text refers to Steps 1, 2, 3, and 4 of the routing logic shown in the previous section.)

Step A. **PC1 sends the packet to its default router.** PC1 first builds the IP packet, with a destination address of PC2's IP address (150.150.4.10). PC1 needs to send the packet to R1 (PC1's default router) because the destination address is on a different subnet. PC1 places the IP packet into an Ethernet frame, with a destination Ethernet address of R1's Ethernet address. PC1 sends the frame onto the Ethernet. (Note that the figure omits the data link trailers.)

Step B. **R1 processes the incoming frame and forwards the packet to R2.** Because the incoming Ethernet frame has a destination MAC of R1's Ethernet MAC, R1 copies the frame off the Ethernet for processing. R1 checks the frame's FCS, and no errors have occurred (Step 1). R1 then discards the Ethernet header and trailer (Step 2). Next, R1 compares the packet's destination address (150.150.4.10) to the routing table and finds the entry for subnet 150.150.4.0—which includes addresses 150.150.4.0 through 150.150.4.255 (Step 3). Because the destination address is in this group, R1 forwards the packet out interface Serial0 to next-hop router R2 (150.150.2.7) after encapsulating the packet in a High-Level Data Link Control (HDLC) frame (Step 4).

Step C. **R2 processes the incoming frame and forwards the packet to R3.** R2 repeats the same general process as R1 when R2 receives the HDLC frame. R2 checks the FCS field and finds that no errors occurred (Step 1). R2 then discards the HDLC header and trailer (Step 2). Next, R2 finds its route for subnet 150.150.4.0—which includes the address range 150.150.4.0–150.150.4.255—and realizes that the packet's destination address 150.150.4.10 matches that route (Step 3). Finally, R2 sends the packet out interface Fast Ethernet 0/0 to next-hop router 150.150.3.1 (R3) after encapsulating the packet in an Ethernet header (Step 4).

Step D. **R3 processes the incoming frame and forwards the packet to PC2.** Like R1 and R2, R3 checks the FCS, discards the old data link header and trailer, and matches its own route for subnet 150.150.4.0. R3's routing table entry for 150.150.4.0 shows that the outgoing interface is R3's Ethernet interface, but there is no next-hop router, because R3 is connected directly to subnet 150.150.4.0. All R3 has to do is encapsulate the packet inside a new Ethernet header and trailer, with a destination Ethernet address of PC2's MAC address, and forward the frame.

Next, this chapter briefly introduces the concepts behind IP routing protocols.

IPv4 Routing Protocols

The routing (forwarding) process depends heavily on having an accurate and up-to-date IP routing table on each router. This section takes another look at routing protocols, considering the goals of a routing protocol, the methods routing protocols use to teach and learn routes, and an example based on the same internetwork shown in the routing example around Figure 4-10.

First, consider the goals of a routing protocol, regardless of how the routing protocol works:

Key Topic

- To dynamically learn and fill the routing table with a route to each subnet in the internetwork.
- If more than one route to a subnet is available, to place the best route in the routing table.
- To notice when routes in the table are no longer valid, and to remove them from the routing table.
- If a route is removed from the routing table and another route through another neighboring router is available, to add the route to the routing table. (Many people view this goal and the preceding one as a single goal.)
- To work quickly when adding new routes or replacing lost routes. (The time between losing the route and finding a working replacement route is called *convergence* time.)
- To prevent routing loops.

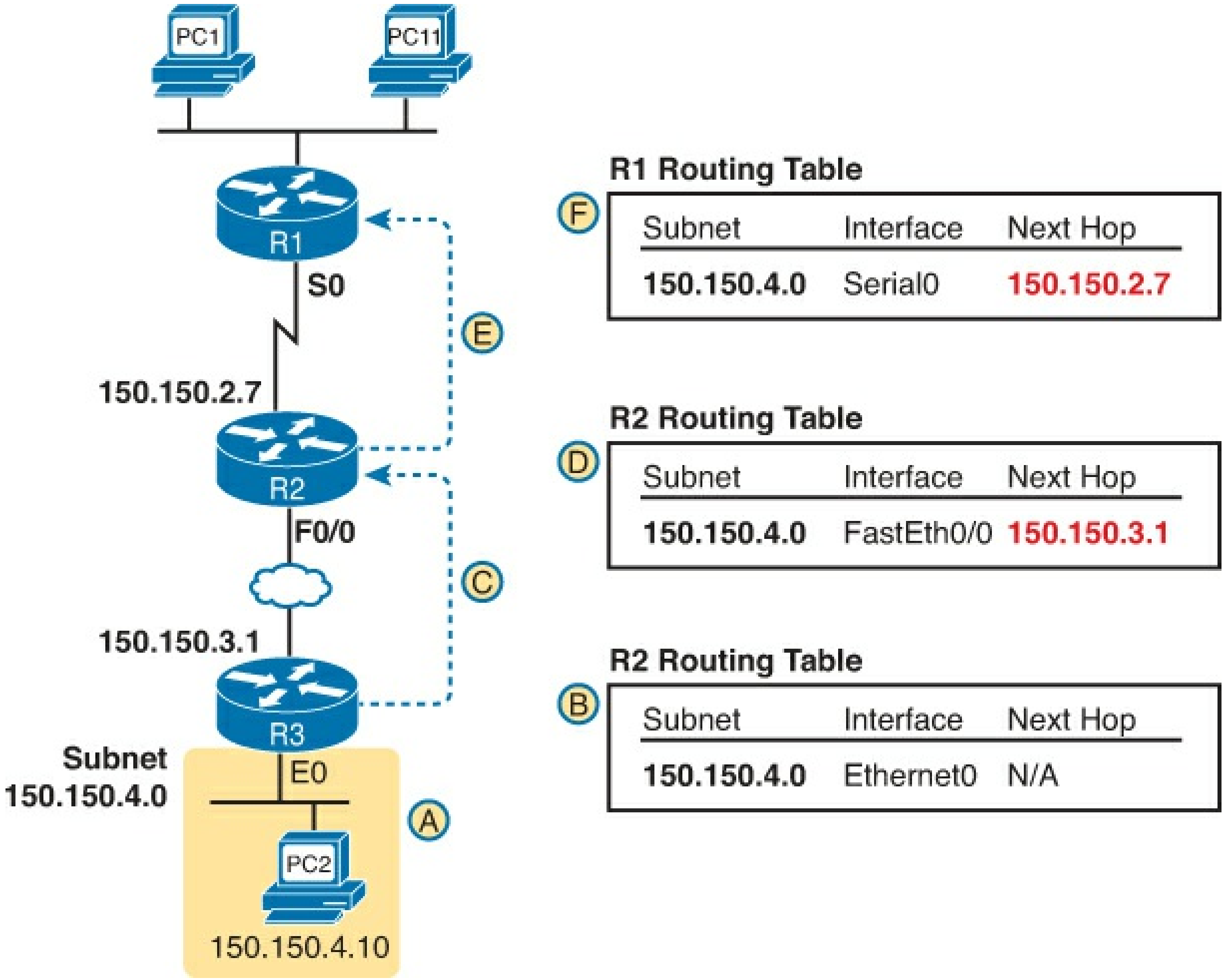
Routing protocols all use some similar ideas to allow routers to learn routing information from each other. Of course, each routing protocol works differently; otherwise, you would not need more than one routing protocol. However, many routing protocols use the same general steps for learning routes:

Step 1. Each router, independent of the routing protocol, adds a route to its routing table for each subnet directly connected to the router.

Step 2. Each router's routing protocol tells its neighbors about the routes in its routing table, including the directly connected routes, and routes learned from other routers.

Step 3. After learning a new route from a neighbor, the router's routing protocol adds a route to its IP routing table, with the next-hop router of that route typically being the neighbor from which the route was learned.

For example, Figure 4-12 shows the same sample network as in Figure 4-11, but now with a focus on how the three routers each learned about subnet 150.150.4.0. Note that routing protocols do more work than is implied in the figure; this figure just focuses on how the routers learn about subnet 150.150.4.0.



R1 Routing Table

Subnet	Interface	Next Hop
150.150.4.0	Serial0	150.150.2.7

R2 Routing Table

Subnet	Interface	Next Hop
150.150.4.0	FastEth0/0	150.150.3.1

R2 Routing Table

Subnet	Interface	Next Hop
150.150.4.0	Ethernet0	N/A

Figure 4-12. Router R1 Learning About Subnet 150.150.4.0

Follow items A through F shown in the figure to see how each router learns its route to 150.150.4.0. All references to Steps 1, 2, and 3 refer to the list just before Figure 4-12.

Step A. Subnet 150.150.4.0 exists as a subnet at the bottom of the figure, connected to router R3.

Step B. R3 adds a connected route for 150.150.4.0 to its IP routing table (Step 1); this happens without help from the routing protocol.

Step C. R3 sends a routing protocol message, called a *routing update*, to R2, causing R2 to learn about subnet 150.150.4.0 (Step 2).

Step D. R2 adds a route for subnet 150.150.4.0 to its routing table (Step 3).

Step E. R2 sends a similar routing update to R1, causing R1 to learn about subnet 150.150.4.0 (Step 2).

Step F. R1 adds a route for subnet 150.150.4.0 to its routing table (Step 3). The route lists R1's own Serial0 as the outgoing interface and R2 as the next-hop router IP address (150.150.2.7).

Chapter 17, "Learning IPv4 Routes with OSPFv2," covers routing protocols in more detail. Next, the final major section of this chapter introduces several additional functions related to how the network layer forwards packets from source to destination through an internetwork.

Other Network Layer Features

The TCP/IP network layer defines many functions beyond the function defined by the IPv4 protocol. Sure, IPv4 plays a huge role in networking today, defining IP addressing and IP routing. However, other protocols and standards, defined in other RFCs, play an important role for network layer functions as well. For example, routing protocols like OSPF exist as separate protocols, defined in separate RFCs.

This last short section of the chapter introduces three other network layer features that should be helpful to you when reading through the rest of this book. These last three topics just help fill in a few holes, helping to give you some perspective, and helping you make sense of later discussions as well. The three topics are

- Domain Name System (DNS)
- Address Resolution Protocol (ARP)
- Ping

Using Names and the Domain Name System

Can you imagine a world in which every time you used an application, you had to think about the other computer and refer to it by IP address? Instead of using easy names like google.com or facebook.com, you would have to remember and type IP addresses, like 74.125.225.5. Certainly, that would not be user friendly and could drive some people away from using computers at all.

Thankfully, TCP/IP defines a way to use *host names* to identify other computers. The user either never thinks about the other computer or refers to the other computer by name. Then, protocols dynamically discover all the necessary information to allow communications based on that name.

For example, when you open a web browser and type in the host name **www.google.com**, your computer does not send an IP packet with destination IP address www.google.com; it sends an IP packet to an IP address used by the web server for Google. TCP/IP needs a way to let a computer find the IP address used by the listed host name, and that method uses the *Domain Name System (DNS)*.

Enterprises use the DNS process to resolve names into the matching IP address, as shown in the example in Figure 4-13. In this case, PC11, on the left, needs to connect to a server named Server1. At some point, the user either types in the name Server1 or some application on PC11 refers to that server by name. At Step 1, PC11 sends a DNS message—a DNS query—to the DNS server. At Step 2, the DNS server sends back a DNS reply that lists Server1's IP address. At Step 3, PC11 can now send an IP packet to destination address 10.1.2.3, the address used by Server1.

Key Topic

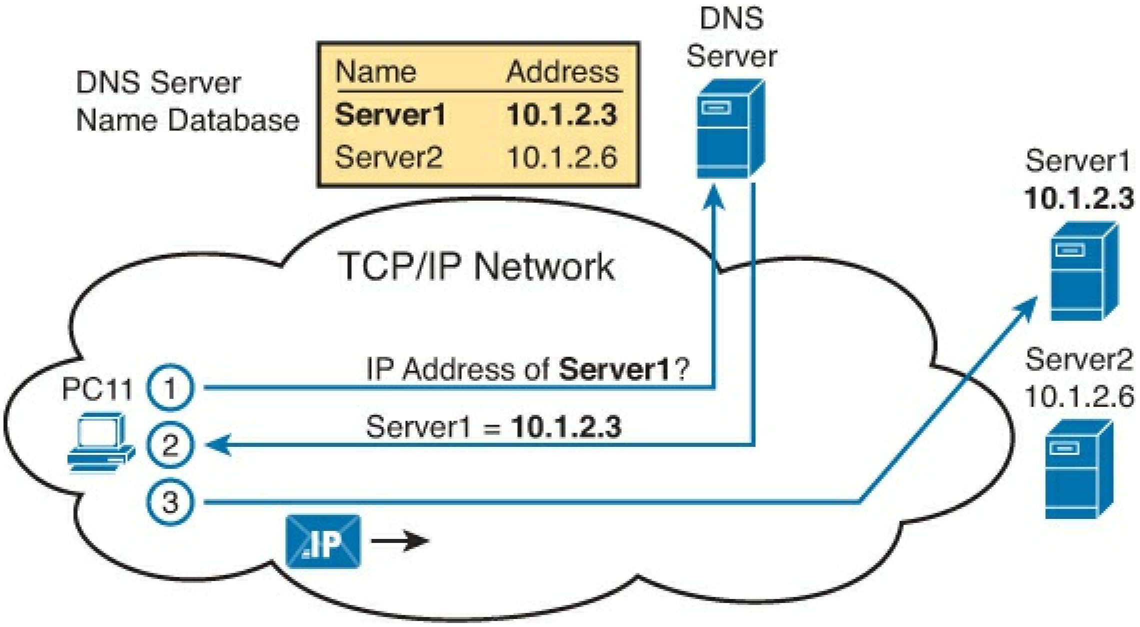


Figure 4-13. Basic DNS Name Resolution Request

Note that the example in Figure 4-13 shows a cloud for the TCP/IP network because the details of the network, including routers, do not matter to the name resolution process. Routers treat the DNS messages just like any other IP packet, routing them based on the destination IP address. For example, at Step 1 in the figure, the DNS query will list the DNS server's IP address as the destination address, which any routers will use to forward the packet.

Finally, DNS defines much more than just a few messages. DNS defines protocols, as well as standards for the text names used throughout the world, and a worldwide set of distributed DNS servers. The domain names that people use every day when web browsing, which look like www.example.com, follow the DNS naming standards. Also, no single DNS server knows all the names and matching IP addresses, but the information is distributed across many DNS servers. So, the DNS servers of the world work together, forwarding queries to each other, until the server that knows the answer supplies the desired IP address information.

The Address Resolution Protocol

IP routing logic requires that hosts and routers encapsulate IP packets inside data link layer frames. In fact, Figure 4-11 shows how every router deencapsulates each IP packet and encapsulates the IP packet inside a new data link frame.

On Ethernet LANs, whenever a host or router needs to encapsulate an IP packet in a new Ethernet frame, the host or router knows all the important facts to build that header—except for the destination MAC address. The host knows the IP address of the next device, either another host IP address or the default router IP address. A router knows the IP route used for forwarding the IP packet, which lists the next router's IP address. However, the hosts and routers do not know those neighboring devices' MAC addresses beforehand.

TCP/IP defines the *Address Resolution Protocol (ARP)* as the method by which any host or router on a LAN can dynamically learn the MAC address of another IP host or router on the same LAN. ARP defines a protocol that includes the *ARP Request*, which is a message that asks the simple request "if this is your IP address, please reply with your MAC address." ARP also defines the *ARP Reply* message, which indeed lists both the original IP address and the matching MAC address.

Figure 4-14 shows an example that uses the same router and host from the bottom part of the earlier Figure 4-11. The figure shows the ARP Request on the left as a LAN broadcast, so all hosts receive the frame. On the right, at Step 2, host PC2 sends back an ARP Reply, identifying PC2's MAC address. The text beside each message shows the contents inside the ARP message itself, which lets PC2 learn R3's IP address and matching MAC address, and R3 learn PC2's IP address and matching MAC address.

Key Topic

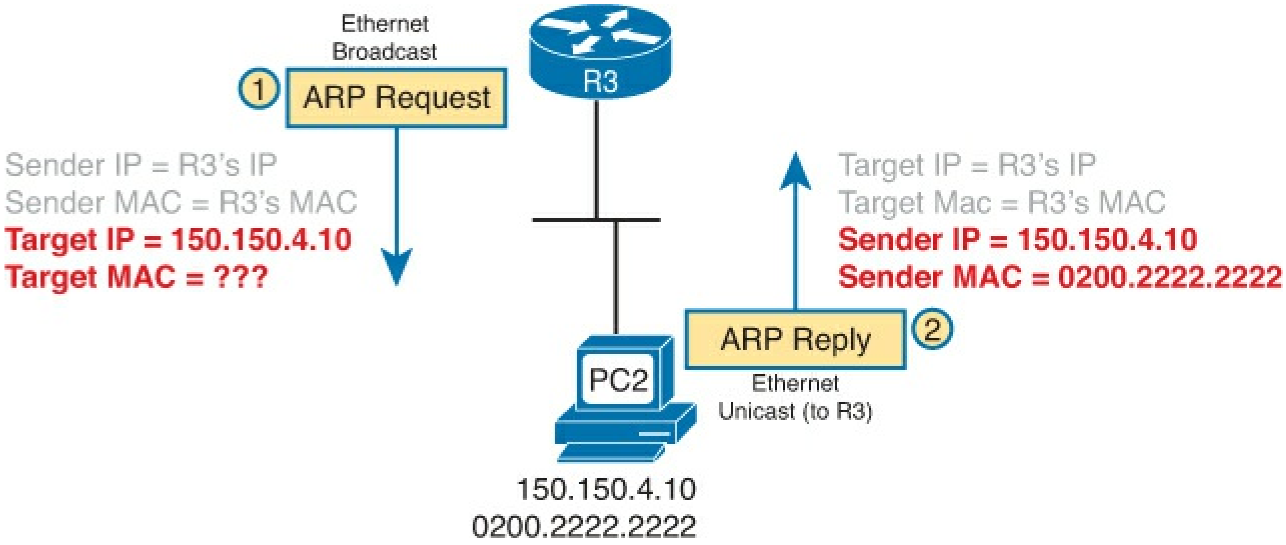

Ethernet
Broadcast
①
ARP Request
R3
Sender IP = R3's IP
Sender MAC = R3's MAC
Target IP = 150.150.4.10
Target MAC = ???
Target IP = R3's IP
Target Mac = R3's MAC
Sender IP = 150.150.4.10
Sender MAC = 0200.2222.2222
ARP Reply
②
Ethernet
Unicast (to R3)
PC2
150.150.4.10
0200.2222.2222

Figure 4-14. Sample ARP Process

Note that hosts remember the ARP results, keeping the information in their *ARP cache* or *ARP table*. A host or router only needs to use ARP occasionally, to build the ARP cache the first time. Each time a host or router needs to send a packet encapsulated in an Ethernet frame, it first checks its ARP cache for the correct IP address and matching MAC address. Hosts and routers will let ARP cache entries time out to clean up the table, so occasional ARP Requests can be seen.

Note

You can see the contents of the ARP cache on most PC operating systems by using the **arp -a** command from a command prompt.

ICMP Echo and the ping Command

After you have implemented a TCP/IP internetwork, you need a way to test basic IP connectivity without relying on any applications to be working. The primary tool for testing basic network connectivity is the **ping** command.

Ping (Packet Internet Groper) uses the *Internet Control Message Protocol (ICMP)*, sending a message called an *ICMP echo request* to another IP address. The computer with that IP address should reply with an *ICMP echo reply*. If that works, you successfully have tested the IP network. In other words, you know that the network can deliver a packet from one host to the other and back. ICMP does not rely on any application, so it really just tests basic IP connectivity—Layers 1, 2, and 3 of the OSI model. Figure 4-15 outlines the basic process.

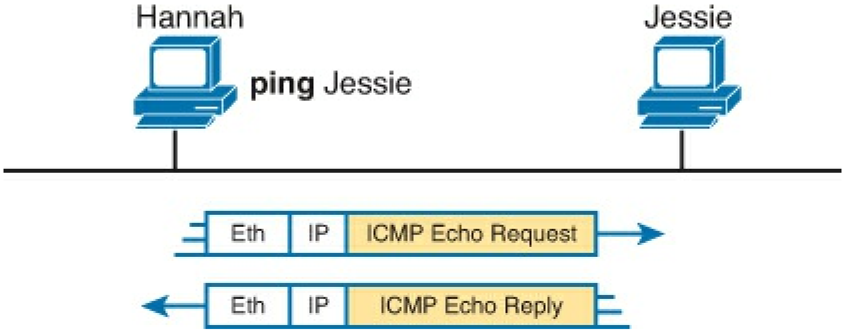

Hannah
Jessie
ping Jessie
Eth
IP
ICMP Echo Request
Eth
IP
ICMP Echo Reply

Figure 4-15. Sample Network, ping **Command**

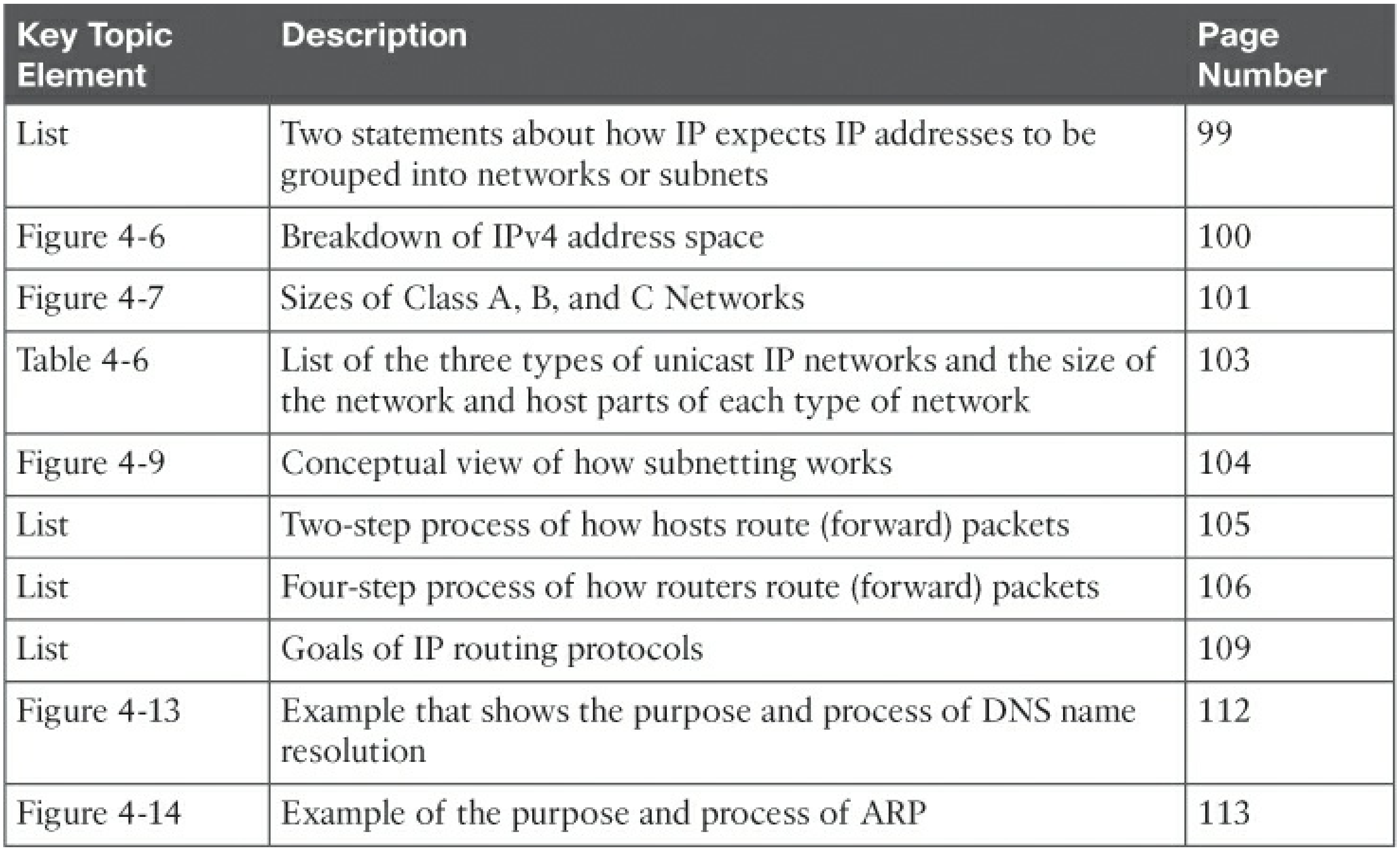
Note that while the **ping** command uses ICMP, ICMP does much more. ICMP defines many messages that devices can use to help manage and control the IP network. Chapter 18, "Configuring and Verifying Host Connectivity," gives you more information about and examples of ping and ICMP.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 4-7 lists these key topics and where each is discussed.

Table 4-7. Key Topics for Chapter 4



Key Topic Element	Description	Page Number
List	Two statements about how IP expects IP addresses to be grouped into networks or subnets	99
Figure 4-6	Breakdown of IPv4 address space	100
Figure 4-7	Sizes of Class A, B, and C Networks	101
Table 4-6	List of the three types of unicast IP networks and the size of the network and host parts of each type of network	103
Figure 4-9	Conceptual view of how subnetting works	104
List	Two-step process of how hosts route (forward) packets	105
List	Four-step process of how routers route (forward) packets	106
List	Goals of IP routing protocols	109
Figure 4-13	Example that shows the purpose and process of DNS name resolution	112
Figure 4-14	Example of the purpose and process of ARP	113

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists for you to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

default router (default gateway)
routing table
IP network
IP subnet
IP packet
routing protocol
dotted-decimal notation (DDN)
IPv4 address
unicast IP address
subnetting
host name
DNS
ARP

ping

Chapter 5. Fundamentals of TCP/IP Transport and Applications

This chapter covers the following exam topics:

Operation of IP Data Networks

Identify common applications and their impact on the network

Predict the data flow between two hosts across a network.

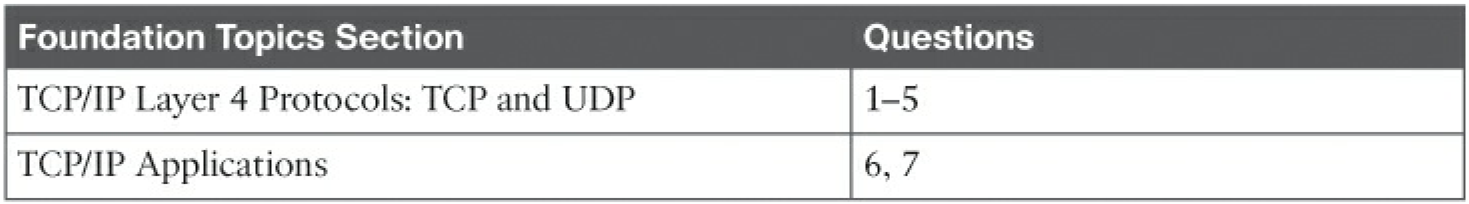
The CCENT and CCNA exams focus mostly on functions at the lower layers of TCP/IP, which define how IP networks can send IP packets from host to host using LANs and WANs. This chapter explains the basics of a few topics that receive less attention on the exams: the TCP/IP transport layer and the TCP/IP application layer. The functions of these higher layers play a big role in real TCP/IP networks, so it helps to have some basic understanding before moving into the rest of the book, where you go deeper into LANs and IP routing.

This chapter begins by examining the functions of two transport layer protocols: Transmission Control Protocol (TCP) and User Datagram Protocol (UDP). The second major section of the chapter examines the TCP/IP application layer, including some discussion of how Domain Name System (DNS) name resolution works.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 5-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
TCP/IP Layer 4 Protocols: TCP and UDP	1–5
TCP/IP Applications	6, 7

1. Which of the following is not a feature of a protocol that is considered to match OSI Layer 4?
    - **a.** Error recovery
    - **b.** Flow control
    - **c.** Segmenting of application data
    - **d.** Conversion from binary to ASCII
2. Which of the following header fields identify which TCP/IP application gets data received by the computer? (Choose two answers.)
    - **a.** Ethernet Type
    - **b.** SNAP Protocol Type
    - **c.** IP Protocol
    - **d.** TCP Port Number
    - **e.** UDP Port Number
3. Which of the following are typical functions of TCP? (Choose four answers.)
    - **a.** Flow Control (windowing)
    - **b.** Error recovery
    - **c.** Multiplexing using port numbers
    - **d.** Routing
    - **e.** Encryption
    - **f.** Ordered data transfer
4. Which of the following functions is performed by both TCP and UDP?
    - **a.** Windowing
    - **b.** Error recovery
    - **c.** Multiplexing using port numbers
    - **d.** Routing
    - **e.** Encryption
    - **f.** Ordered data transfer
5. What do you call data that includes the Layer 4 protocol header, and data given to Layer 4 by the upper layers, not including any headers and trailers from Layers 1 to 3? (Choose two answers.)
    - **a.** L3PDU

b. Chunk
c. Segment
d. Packet
e. Frame
f. L4PDU

6. In the URL http://www.certskills.com/ICND1, which part identifies the web server?

a. http
b. www.certskills.com
c. certskills.com
d. http://www.certskills.com
e. The file name.html includes the host name.

7. When comparing VoIP with an HTTP-based mission-critical business application, which of the following statements are accurate about the quality of service needed from the network? (Choose two answers.)

a. VoIP needs better (lower) packet loss.
b. HTTP needs less bandwidth.
c. HTTP needs better (lower) jitter.
d. VoIP needs better (lower) delay.

Answers to the "Do I Know This Already?" quiz:

1 D **2** D and E **3** A, B, C, and F **4** C **5** C and F **6** B **7** A and D

Foundation Topics

TCP/IP Layer 4 Protocols: TCP and UDP

The OSI transport layer (Layer 4) defines several functions, the most important of which are error recovery and flow control. Likewise, the TCP/IP transport layer protocols also implement these same types of features. Note that both the OSI model and the TCP/IP model call this layer the transport layer. But as usual, when referring to the TCP/IP model, the layer name and number are based on OSI, so any TCP/IP transport layer protocols are considered Layer 4 protocols.

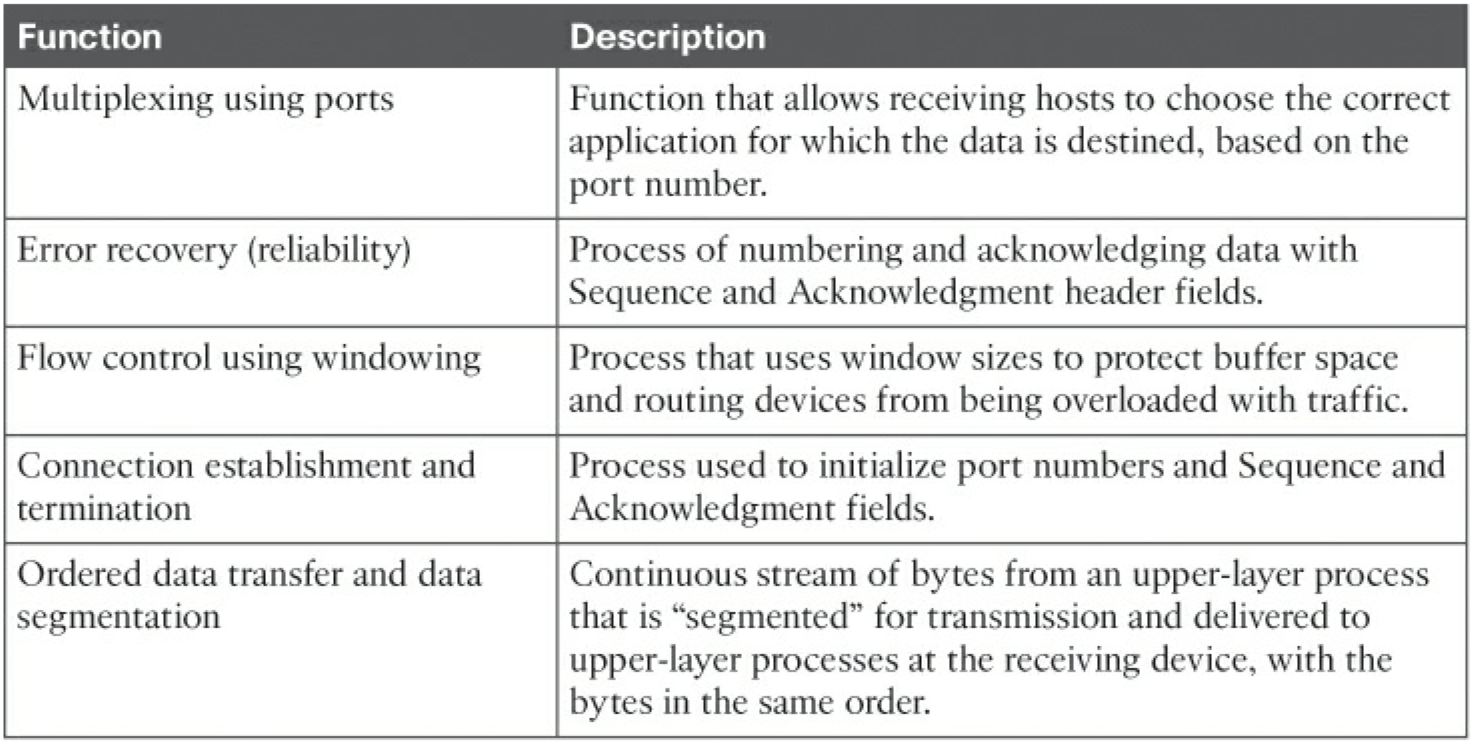
The key difference between TCP and UDP is that TCP provides a wide variety of services to applications, whereas UDP does not. For example, routers discard packets for many reasons, including bit errors, congestion, and instances in which no correct routes are known. As you have read already, most data link protocols notice errors (a process called *error detection*) but then discard frames that have errors. TCP provides retransmission (error recovery) and helps to avoid congestion (flow control), whereas UDP does not. As a result, many application protocols choose to use TCP.

However, do not let UDP's lack of services make you think that UDP is worse than TCP. By providing fewer services, UDP needs fewer bytes in its header compared to TCP, resulting in fewer bytes of overhead in the network. UDP software does not slow down data transfer in cases where TCP can purposefully slow down. Also, some applications, notably today Voice over IP (VoIP) and video over IP, do not need error recovery, so they use UDP. So, UDP also has an important place in TCP/IP networks today.

Table 5-2 lists the main features supported by TCP and/or UDP. Note that only the first item listed in the table is supported by UDP, whereas all items in the table are supported by TCP.

Key Topic

Table 5-2. TCP/IP Transport Layer Features



Function	Description
Multiplexing using ports	Function that allows receiving hosts to choose the correct application for which the data is destined, based on the port number.
Error recovery (reliability)	Process of numbering and acknowledging data with Sequence and Acknowledgment header fields.
Flow control using windowing	Process that uses window sizes to protect buffer space and routing devices from being overloaded with traffic.
Connection establishment and termination	Process used to initialize port numbers and Sequence and Acknowledgment fields.
Ordered data transfer and data segmentation	Continuous stream of bytes from an upper-layer process that is "segmented" for transmission and delivered to upper-layer processes at the receiving device, with the bytes in the same order.

Next, this section describes the features of TCP, followed by a brief comparison to UDP.

Transmission Control Protocol

Each TCP/IP application typically chooses to use either TCP or UDP based on the application's requirements. For example, TCP provides error recovery, but to do so, it consumes more bandwidth and uses more processing cycles. UDP does not perform error recovery, but it takes less bandwidth and uses fewer processing cycles. Regardless of which of these two TCP/IP transport layer protocols the application chooses to use, you should understand the basics of how each of these transport layer protocols works.

TCP, as defined in RFC 793, accomplishes the functions listed in Table 5-2 through mechanisms at the endpoint computers. TCP relies on IP for end-to-end delivery of the data, including routing issues. In other words, TCP performs only part of the functions necessary to deliver the data between applications. Also, the role that it plays is directed toward providing services for the applications that sit at the endpoint computers. Regardless of whether two computers are on the same Ethernet, or are separated by the entire Internet, TCP performs its functions the same way.

Figure 5-1 shows the fields in the TCP header. Although you don't need to memorize the names of the fields or their locations, the rest of this section refers to several of the fields, so the entire header is included here for reference.

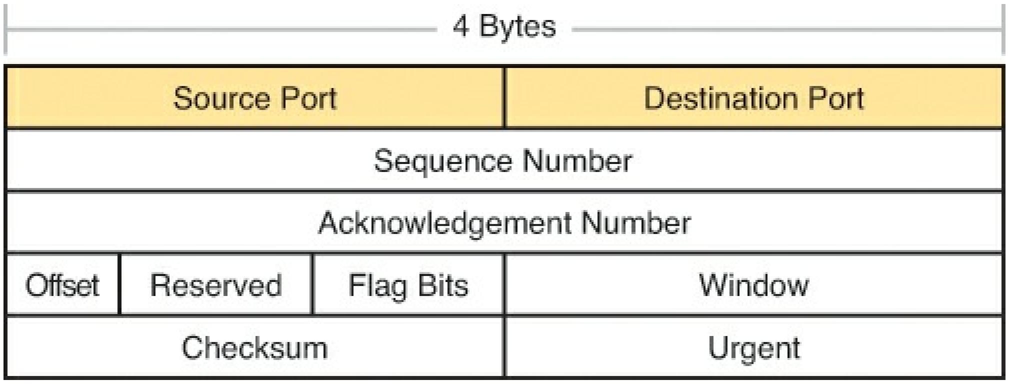


Figure 5-1. TCP Header Fields

The message created by TCP that begins with the TCP header, followed by any application data, is called a *TCP segment*. Alternately, the more generic term *Layer 4 PDU*, or *L4PDU*, can also be used.

Multiplexing Using TCP Port Numbers

TCP and UDP both use a concept called *multiplexing*. Therefore, this section begins with an explanation of multiplexing with TCP and UDP. Afterward, the unique features of TCP are explored.

Multiplexing by TCP and UDP involves the process of how a computer thinks when receiving data. The computer might be running many applications, such as a web browser, an email package, or an Internet VoIP application (for example, Skype). TCP and UDP multiplexing tells the receiving computer to which application to give the received data.

Some examples will help make the need for multiplexing obvious. The sample network consists of two PCs, labeled Hannah and Jessie. Hannah uses an application that she wrote to send advertisements that appear on Jessie's screen. The application sends a new ad to Jessie every 10 seconds. Hannah uses a second application, a wire-transfer application, to send Jessie some money. Finally, Hannah uses a web browser to access the web server that runs on Jessie's PC. The ad application and wire-transfer application are imaginary, just for this example. The web application works just like it would in real life.

Figure 5-2 shows the sample network, with Jessie running three applications:

- A UDP-based ad application
- A TCP-based wire-transfer application
- A TCP web server application

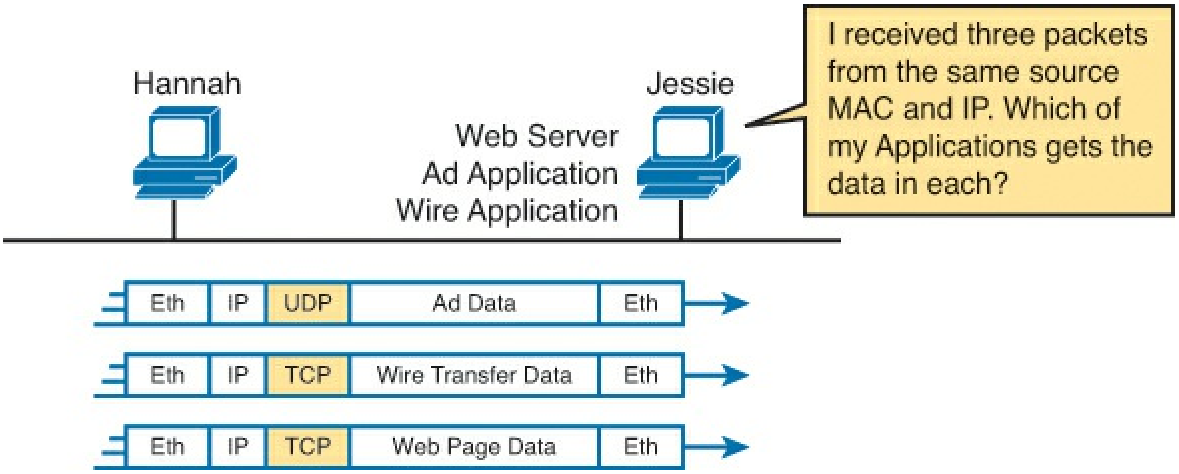

Hannah
Jessie
Web Server
Ad Application
Wire Application
I received three packets from the same source MAC and IP. Which of my Applications gets the data in each?
Eth
IP
UDP
Ad Data
Eth
Eth
IP
TCP
Wire Transfer Data
Eth
Eth
IP
TCP
Web Page Data
Eth

Figure 5-2. Hannah Sending Packets to Jessie, with Three Applications

Jessie needs to know which application to give the data to, but *all three packets are from the same Ethernet and IP address*. You might think that Jessie could look at whether the packet contains a UDP or TCP header, but as you see in the figure, two applications (wire transfer and web) are using TCP.

TCP and UDP solve this problem by using a port number field in the TCP or UDP header, respectively. Each of Hannah's TCP and UDP segments uses a different *destination port number* so that Jessie knows which application to give the data to. Figure 5-3 shows an example.

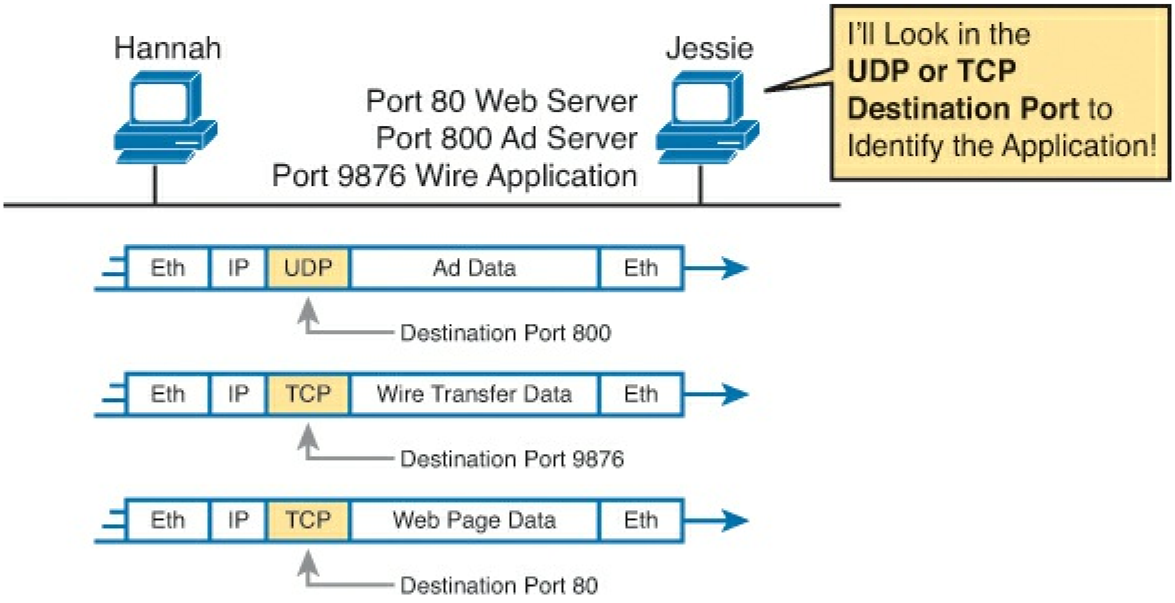

Hannah
Jessie
Port 80 Web Server
Port 800 Ad Server
Port 9876 Wire Application
I'll Look in the **UDP or TCP Destination Port** to Identify the Application!
Eth
IP
UDP
Ad Data
Eth
Destination Port 800
Eth
IP
TCP
Wire Transfer Data
Eth
Destination Port 9876
Eth
IP
TCP
Web Page Data
Eth
Destination Port 80

Figure 5-3. Hannah Sending Packets to Jessie, with Three Applications Using Port Numbers to Multiplex

Multiplexing relies on a concept called a *socket*. A socket consists of three things:

- An IP address
- A transport protocol
- A port number

So, for a web server application on Jessie, the socket would be (10.1.1.2, TCP, port 80) because, by default, web servers use the well-known port 80. When Hannah's web browser connects to the web server, Hannah uses a socket as well—possibly one like this: (10.1.1.1, TCP, 1030). Why 1030? Well, Hannah just needs a port number that is unique on Hannah, so Hannah sees that port 1030 is available and uses it. In fact, hosts typically allocate *dynamic port numbers* starting at 1024 because the ports below 1024 are reserved for well-known applications.

In Figure 5-3, Hannah and Jessie use three applications at the same time—hence, three socket connections are open. Because a socket on a single computer should be unique, a connection between two sockets should identify a unique connection between two computers. This uniqueness means that you can use multiple applications at the same time, talking to applications running on the same or different computers. Multiplexing, based on sockets, ensures that the data is delivered to the correct applications. Figure 5-4 shows the three socket connections between Hannah and Jessie.

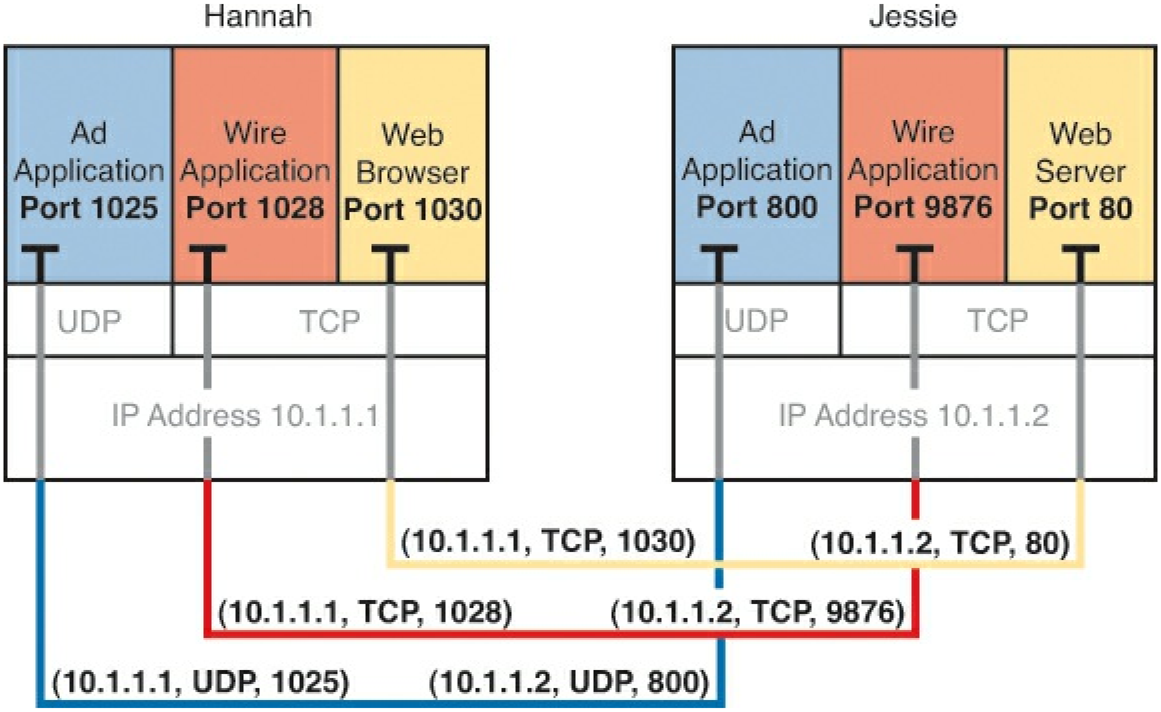


Figure 5-4. Connections Between Sockets

Port numbers are a vital part of the socket concept. Well-known port numbers are used by servers; other port numbers are used by clients. Applications that provide a service, such as FTP, Telnet, and web servers, open a socket using a well-known port and listen for connection requests. Because these connection requests from clients are required to include both the source and destination port numbers, the port numbers used by the servers must be well-known. Therefore, each service uses a specific well-known port number. The well-known ports are listed at www.iana.org/assignments/service-names-port-numbers/service-names-port-numbers.txt.

On client machines, where the requests originate, any locally unused port number can be allocated. The result is that each client on the same host uses a different port number, but a server uses the same port number for all connections. For example, 100 web browsers on the same host computer could each connect to a web server, but the web server with 100 clients connected to it would have only one socket and, therefore, only one port number (port 80, in this case). The server can tell which packets are sent from which of the 100 clients by looking at the source port of received TCP segments. The server can send data to the correct web client (browser) by sending data to that same port number listed as a destination port. The combination of source and destination sockets allows all participating hosts to distinguish between the data's source and destination. Although the example explains the concept using 100 TCP connections, the same port-numbering concept applies to UDP sessions in the same way.

> **Note**
>
> You can find all RFCs online at www.isi.edu/in-notes/rfc*xxxx*.txt, where *xxxx* is the number of the RFC. If you do not know the number of the RFC, you can try searching by topic at www.rfc-editor.org.

Popular TCP/IP Applications

Throughout your preparation for the CCNA exams, you will come across a variety of TCP/IP applications. You should at least be aware of some of the applications that can be used to help manage and control a network.

The World Wide Web (WWW) application exists through web browsers accessing the content available on web servers. Although it is often thought of as an end-user application, you can actually use WWW to manage a router or switch. You enable a web server function in the router or switch and use a browser to access the router or switch.

The Domain Name System (DNS) allows users to use names to refer to computers, with DNS being used to find the corresponding IP addresses. DNS also uses a client/server model, with DNS servers being controlled by networking personnel and DNS client functions being part of most any device that uses TCP/IP today. The client simply asks the DNS server to supply the IP address that corresponds to a given name.

Simple Network Management Protocol (SNMP) is an application layer protocol used specifically for network device management. For example, Cisco supplies a large variety of network management products, many of them in the Cisco Prime network management software product family. They can be used to query, compile, store, and display information about a network's operation. To query the network devices, Cisco Prime software mainly uses SNMP protocols.

Traditionally, to move files to and from a router or switch, Cisco used Trivial File Transfer Protocol (TFTP). TFTP defines a protocol for basic file transfer—hence the word *trivial*. Alternatively, routers and switches can use File Transfer Protocol (FTP), which is a much more functional protocol, to transfer files. Both work well for moving files into and out of Cisco devices. FTP allows many more features, making it a good choice for the general end-user population. TFTP client and server applications are very simple, making them good tools as embedded parts of networking devices.

Some of these applications use TCP, and some use UDP. For example, Simple Mail Transfer Protocol (SMTP) and Post Office Protocol version 3 (POP3), both used for transferring mail, require guaranteed delivery, so they use TCP. Regardless of which transport layer protocol is used, applications use a well-known port number so that clients know which port to attempt to connect to. Table 5-3 lists several popular applications and their well-known port numbers.

Key Topic

Table 5-3. Popular Applications and Their Well-Known Port Numbers

Port Number	Protocol	Application
20	TCP	FTP data
21	TCP	FTP control
22	TCP	SSH
23	TCP	Telnet
25	TCP	SMTP
53	UDP, TCP	DNS
67, 68	UDP	DHCP
69	UDP	TFTP
80	TCP	HTTP (WWW)
110	TCP	POP3
161	UDP	SNMP
443	TCP	SSL

Connection Establishment and Termination

TCP connection establishment occurs before any of the other TCP features can begin their work. Connection establishment refers to the process of initializing sequence and acknowledgment fields and agreeing on the port numbers used. Figure 5-5 shows an example of connection establishment flow.

Key Topic

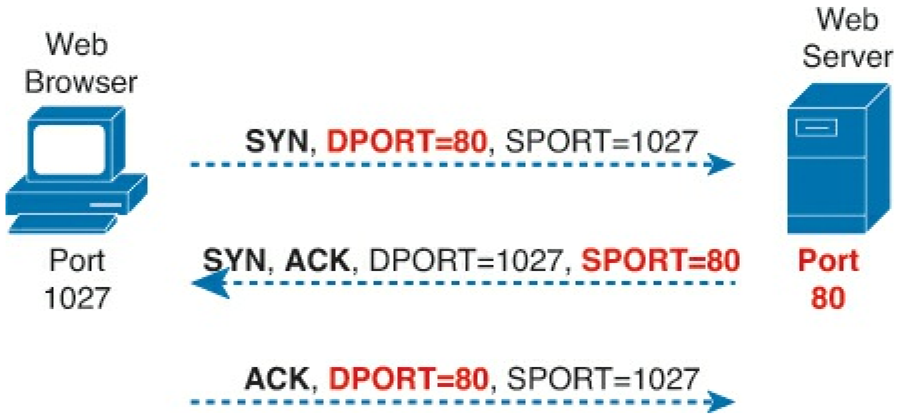

Web Browser
Web Server
SYN, DPORT=80, SPORT=1027
SYN, ACK, DPORT=1027, SPORT=80
ACK, DPORT=80, SPORT=1027
Port 1027
Port 80

Figure 5-5. TCP Connection Establishment

This three-way connection establishment flow (also called a three-way handshake) must complete before data transfer can begin. The connection exists between the two sockets, although the TCP header has no single socket field. Of the three parts of a socket, the IP addresses are implied based on the source and destination IP addresses in the IP header. TCP is implied because a TCP header is in use, as specified by the protocol field value in the IP header. Therefore, the only parts of the socket that need to be encoded in the TCP header are the port numbers.

TCP signals connection establishment using 2 bits inside the flag fields of the TCP header. Called the SYN and ACK flags, these bits have a particularly interesting meaning. SYN means "synchronize the sequence numbers," which is one necessary component in initialization for TCP.

Figure 5-6 shows TCP connection termination. This four-way termination sequence is straightforward and uses an additional flag, called the *FIN bit*. (FIN is short for "finished," as you might guess.) One interesting note: Before the device on the right sends the third TCP segment in the sequence, it notifies the application that the connection is coming down. It then waits on an acknowledgment from the application before sending the third segment in the figure. Just in case the application takes some time to reply, the PC on the right sends the second flow in the figure, acknowledging that the other PC wants to take down the connection. Otherwise, the PC on the left might resend the first segment repeatedly.

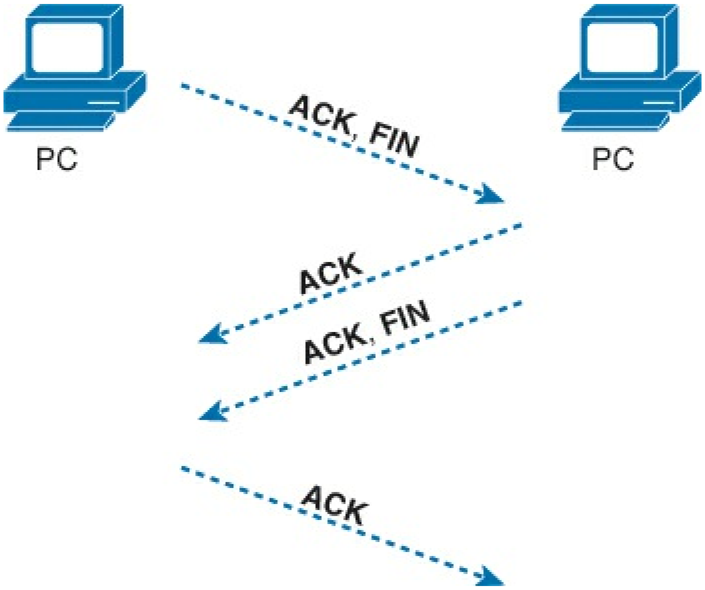


Figure 5-6. TCP Connection Termination

TCP establishes and terminates connections between the endpoints, whereas UDP does not. Many protocols operate under these same concepts, so the terms *connection-oriented* and *connectionless* are used to refer to the general idea of each. More formally, these terms can be defined as follows:

Key Topic

- **Connection-oriented protocol:** A protocol that requires an exchange of messages before data transfer begins, or that has a required preestablished correlation between two endpoints.
- **Connectionless protocol:** A protocol that does not require an exchange of messages and that does not require a preestablished correlation between two endpoints.

User Datagram Protocol

UDP provides a service for applications to exchange messages. Unlike TCP, UDP is connectionless and provides no reliability, no windowing, no reordering of the received data, and no segmentation of large chunks of data into the right size for transmission. However, UDP provides some functions of TCP, such as data transfer and multiplexing using port numbers, and it does so with fewer bytes of overhead and less processing required than TCP.

UDP data transfer differs from TCP data transfer in that no reordering or recovery is accomplished. Applications that use UDP are tolerant of the lost data, or they have some application mechanism to recover lost data. For example, VoIP uses UDP because if a voice packet is lost, by the time the loss could be noticed and the packet retransmitted, too much delay would have occurred, and the voice would be unintelligible. Also, DNS requests use UDP because the user will retry an operation if the DNS resolution fails. As another example, the Network File System (NFS), a remote file system application, performs recovery with application layer code, so UDP features are acceptable to NFS.

Figure 5-7 shows the UDP header format. Most importantly, note that the header includes source and destination port fields, for the same purpose as TCP. However, the UDP has only 8 bytes, in comparison to the 20-byte TCP header shown in Figure 5-1. UDP needs a shorter header than TCP simply because UDP has less work to do.

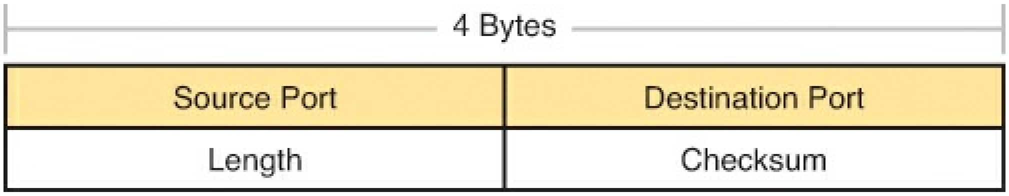


Figure 5-7. UDP Header

TCP/IP Applications

The whole goal of building an enterprise network, or connecting a small home or office network to the Internet, is to use applications—applications such as web browsing, text messaging, email, file downloads, voice, and video. This section examines a few issues related to network design in light of the applications expected in an internetwork. This is followed by a much deeper look at one particular application—web browsing using Hypertext Transfer Protocol (HTTP).

QoS Needs and the Impact of TCP/IP Applications

Applications need to send data over a TCP/IP internetwork. However, they need more than the ability to move the data from one application on one device to another application on another device. That communication has different characteristics, or qualities, and the networking world refers to these qualities as quality of service (QoS).

QoS in general defines the quality of the data transfer between two applications and in the network as a whole. QoS often breaks down these qualities into four competing characteristics:

Bandwidth: The volume of bits per second needed for the application to work well; it can be biased with more volume in one direction, or balanced.

Delay: The amount of time it takes one IP packet to flow from sender to receiver.

Jitter: The variation in delay.

Loss: The percentage of packets discarded by the network before they reach the destination, which when using TCP, requires a retransmission.

Today's TCP/IP internetworks support many types of applications, and each type has different QoS requirements. The next few pages look at the QoS requirements for three general categories of applications: batch, interactive, and real-time.

Defining Interactive and Batch Applications

TCP/IP networks began in the 1970s and 1980s with data applications only, with no widely used voice and video applications. Data applications send bits, and the bits represent data: text to be displayed for a user, graphical images to be displayed for a user, customer information, and so on.

Data applications have different QoS requirements depending on whether they are interactive or batch. Interactive data applications usually have a human user at one end of a flow, and the IP packets must flow in both directions for meaningful work to happen. For example, the user takes some action, sending a packet to a server; before the user sees more data on the screen, the server must send a packet back. So, the delay and jitter have a big impact on the user experience.

Batch applications focus more on the bandwidth between two software processes. Batch applications often do not even have a human in the picture. For example, you can have an application on your device that backs up your device data overnight, copying it to some server in the network. You personally might not care how long it takes, but the IT department cares how much bandwidth (how many bits/second) is needed. Why? The IT department might need to support thousands of devices that need to do their backups between 2 a.m. and 5 a.m. each day, so it has to build a network with enough bandwidth to meet that need.

Real-Time Voice and Video Applications

Most modern enterprise TCP/IP internetworks support voice applications as well. Most commonly, the network includes IP phones, which are telephones that connect to the TCP/IP network using an Ethernet or wireless LAN connection. The phone sends the voice as bits inside IP packets, as shown in Figure 5-8.

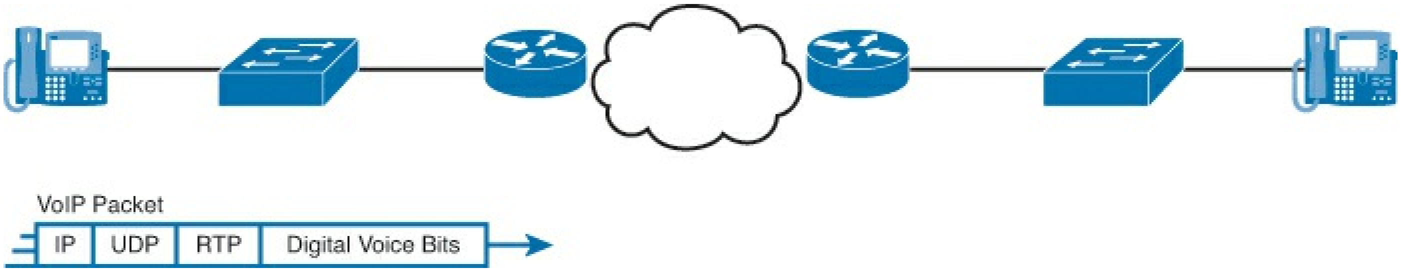


Figure 5-8. IP Packet Sent by a Voice Call

Note

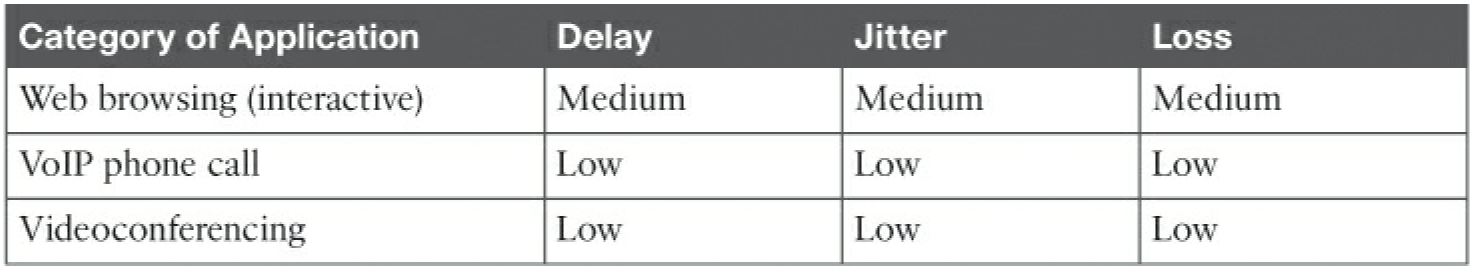
Sending voice traffic as bits inside an IP packet is generally called *Voice over IP (VoIP)*, while the use of telephones that connect to LANs as shown in Figure 5-8 is called *IP telephony*.

While a phone call between two IP phones has similar kinds of QoS requirements as an interactive data application, because the QoS requirements are much higher, voice is considered to be a real-time application instead of an interactive application. For example, a one-way network delay of 1 second works well for most web-browsing experiences. However, for a quality voice call, that same one-way delay needs to be less than 0.2 seconds. Also, interactive applications do not suffer much when packets are lost in transit, but a real-time voice call does suffer, with less voice quality.

The QoS requirements for video are similar to those for voice. Like voice, two-way video applications, like videoconferencing, require low delay, low jitter, and low loss.

Table 5-4 compares the QoS requirements of three example applications: interactive web browsing, real-time voice, and real-time video. Use the table to review the comparisons between data applications versus voice and video, as opposed to using it as a set of random facts to memorize.

Table 5-4. Comparing Interactive and Real-Time Application Requirements



Category of Application	Delay	Jitter	Loss
Web browsing (interactive)	Medium	Medium	Medium
VoIP phone call	Low	Low	Low
Videoconferencing	Low	Low	Low

To support the QoS requirements of the various applications, routers and switches can be configured with a wide variety of QoS tools. They are beyond the scope of the CCNA exams (but are covered on several of the Cisco professional-level certifications). However, the QoS tools must be used for a modern network to be able to support high-quality VoIP and video over IP.

Next, we examine the most popular application layer protocol for interactive data applications today—HTTP and the World Wide Web (WWW). The goal is to show one example of how application layer protocols work.

The World Wide Web, HTTP, and SSL

The *World Wide Web (WWW)* consists of all the Internet-connected web servers in the world, plus all Internet-connected hosts with web browsers. *Web servers*, which consist of web server software running on a computer, store information (in the form of *web pages*) that might be useful to different people. *Web browsers*, which is software installed on an end user's computer, provide the means to connect to a web server and display the web pages stored on the web server.

Note

Although most people use the term *web browser*, or simply *browser*, web browsers are also called *web clients*, because they obtain a service from a web server.

For this process to work, several specific application layer functions must occur. The user must somehow identify the server, the specific web page, and the protocol used to get the data from the server. The client must find the server's IP address, based on the server's name, typically using DNS. The client must request the web page, which actually consists of multiple separate files, and the server must send the files to the web browser. Finally, for electronic commerce (e-commerce) applications, the transfer of data, particularly sensitive financial data, needs to be secure. The following sections address each of these functions.

Uniform Resource Locators

For a browser to display a web page, the browser must identify the server that has the web page, plus other information that identifies the particular web page. Most web servers have many web pages. For example, if you use a web browser to browse www.cisco.com and you click around that web page, you'll see another web page. Click again, and you'll see another web page. In each case, the clicking action identifies the server's IP address and the specific web page, with the details mostly hidden from you. (These clickable items on a web page, which in turn bring you to another web page, are called *links*.)

The browser user can identify a web page when you click something on a web page or when you enter a *Uniform Resource Locator (URL)* (often called a *web address* and sometimes a universal resource locator) in the browser's address area. Both options—clicking a link and entering a URL—refer to a URL, because when you click a link on a web page, that link actually refers to a URL.

Note

Most browsers support some way to view the hidden URL referenced by a link. In several browsers, hover the mouse pointer over a link, right-click, and select **Properties**. The pop-up window should display the URL to which the browser would be directed if you clicked that link.

Each URL defines the protocol used to transfer data, the name of the server, and the particular web page on that server. The URL can be broken into three parts:

- The protocol is listed before the //.
- The host name is listed between the // and the /.
- The name of the web page is listed after the /.

For example, consider the following:

http://www.certskills.com/ICND1

In this case, the protocol is *Hypertext Transfer Protocol (HTTP)*, the host name is www.certskills.com, and the name of the web page is ICND1.

Finding the Web Server Using DNS

As mentioned in Chapter 4, "Fundamentals of IPv4 Addressing and Routing," a host can use DNS to discover the IP address that corresponds to a particular host name. Although URLs can include the IP address of the web server instead of the name of the web server, URLs typically list the host name. So, before the browser can send a packet to the web server, the browser typically needs to resolve the name in the URL to that name's corresponding IP address.

To pull together several concepts, Figure 5-9 shows the DNS process as initiated by a web browser, as well as some other related information. From a basic perspective, the user enters the URL (http://www.cisco.com*go*learningnetwork), resolves the www.cisco.com name into the correct IP address, and starts sending packets to the web server.

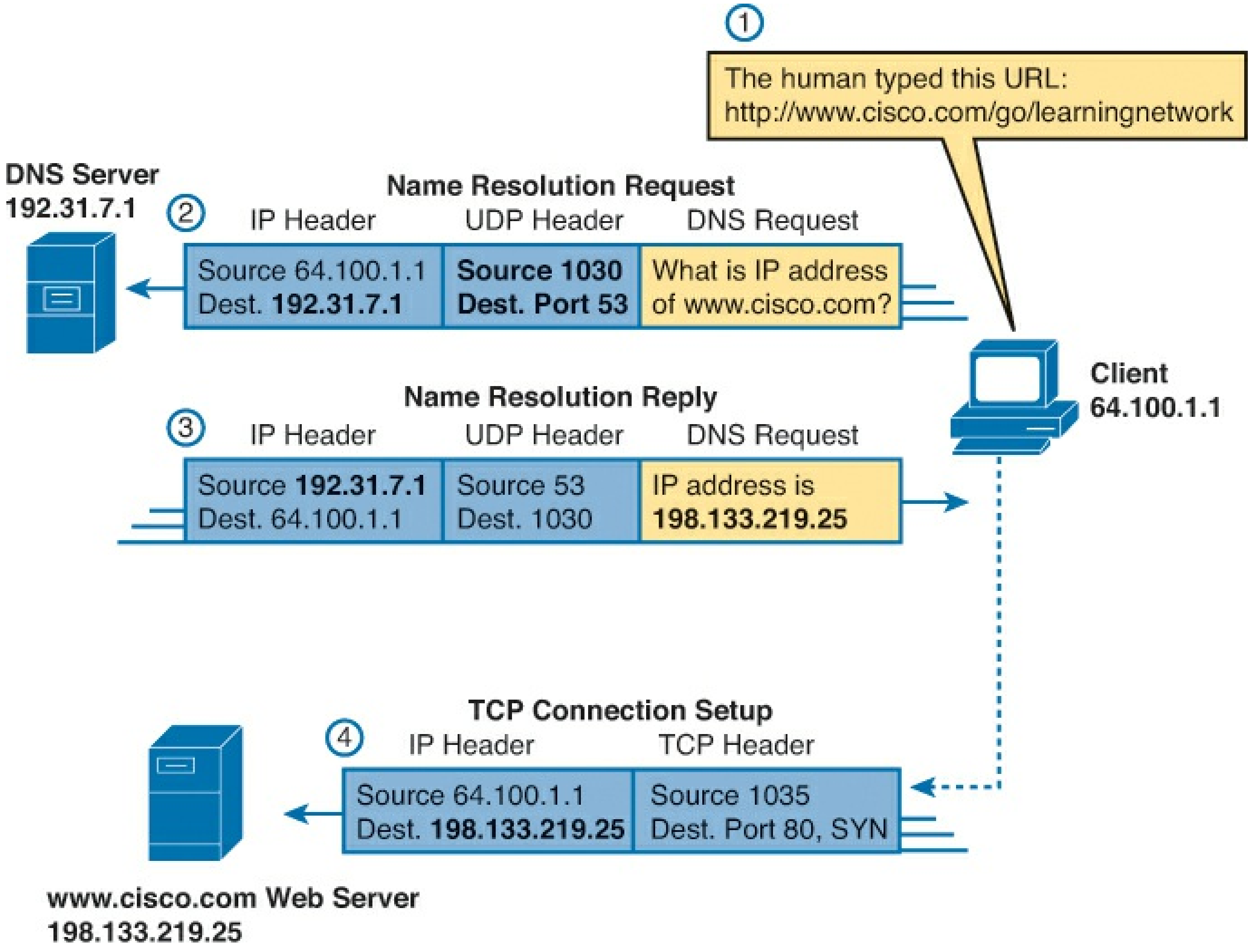

①
The human typed this URL:
http://www.cisco.com/go/learningnetwork
DNS Server
192.31.7.1
②
Name Resolution Request
IP Header
UDP Header
DNS Request
Source 64.100.1.1
Dest. 192.31.7.1
Source 1030
Dest. Port 53
What is IP address
of www.cisco.com?
Client
64.100.1.1
Name Resolution Reply
③
IP Header
UDP Header
DNS Request
Source 192.31.7.1
Dest. 64.100.1.1
Source 53
Dest. 1030
IP address is
198.133.219.25
TCP Connection Setup
④
IP Header
TCP Header
Source 64.100.1.1
Dest. 198.133.219.25
Source 1035
Dest. Port 80, SYN
www.cisco.com Web Server
198.133.219.25

Figure 5-9. DNS Resolution and Requesting a Web Page

The steps shown in the figure are as follows:

1. The user enters the URL, http://www.cisco.com*go*learningnetwork, into the browser's address area.
2. The client sends a DNS request to the DNS server. Typically, the client learns the DNS server's IP address through DHCP. Note that the DNS request uses a UDP header, with a destination port of the DNS well-known port of 53. (See Table 5-3, earlier in this chapter, for a list of popular well-known ports.)
3. The DNS server sends a reply, listing IP address 198.133.219.25 as www.cisco.com's IP address. Note also that the reply shows a destination IP address of 64.100.1.1, the client's IP address. It also shows a UDP header, with source port 53; the source port is 53 because the data is sourced, or sent by, the DNS server.
4. The client begins the process of establishing a new TCP connection to the web server. Note that the destination IP address is the just-learned IP address of the web server. The packet includes a TCP header, because HTTP uses TCP.

Also note that the destination TCP port is 80, the well-known port for HTTP. Finally, the SYN bit is shown, as a reminder that the TCP connection establishment process begins with a TCP segment with the SYN bit turned on (binary 1).

At this point in the process, the web browser is almost finished setting up a TCP connection to the web server. The next section picks up the story at that point, examining how the web browser then gets the files that comprise the desired web page.

Transferring Files with HTTP

After a web client (browser) has created a TCP connection to a web server, the client can begin requesting the web page from the server. Most often, the protocol used to transfer the web page is HTTP. The HTTP application layer protocol, defined in RFC 2616, defines how files can be transferred between two computers. HTTP was specifically created for the purpose of transferring files between web servers and web clients.

HTTP defines several commands and responses, with the most frequently used being the HTTP GET request. To get a file from a web server, the client sends an HTTP GET request to the server, listing the filename. If the server decides to send the file, the server sends an HTTP GET response, with a return code of 200 (meaning "OK"), along with the file's contents.

Note

Many return codes exist for HTTP requests. For example, when the server does not have the requested file, it issues a return code of 404, which means "file not found." Most web browsers do not show the specific numeric HTTP return codes, instead displaying a response such as "page not found" in reaction to receiving a return code of 404.

Web pages typically consist of multiple files, called *objects*. Most web pages contain text as well as several graphical images, animated advertisements, and possibly voice or video. Each of these components is stored as a different object (file) on the web server. To get them all, the web browser gets the first file. This file can (and typically does) include references to other URLs, so the browser then also requests the other objects. Figure 5-10 shows the general idea, with the browser getting the first file and then two others.

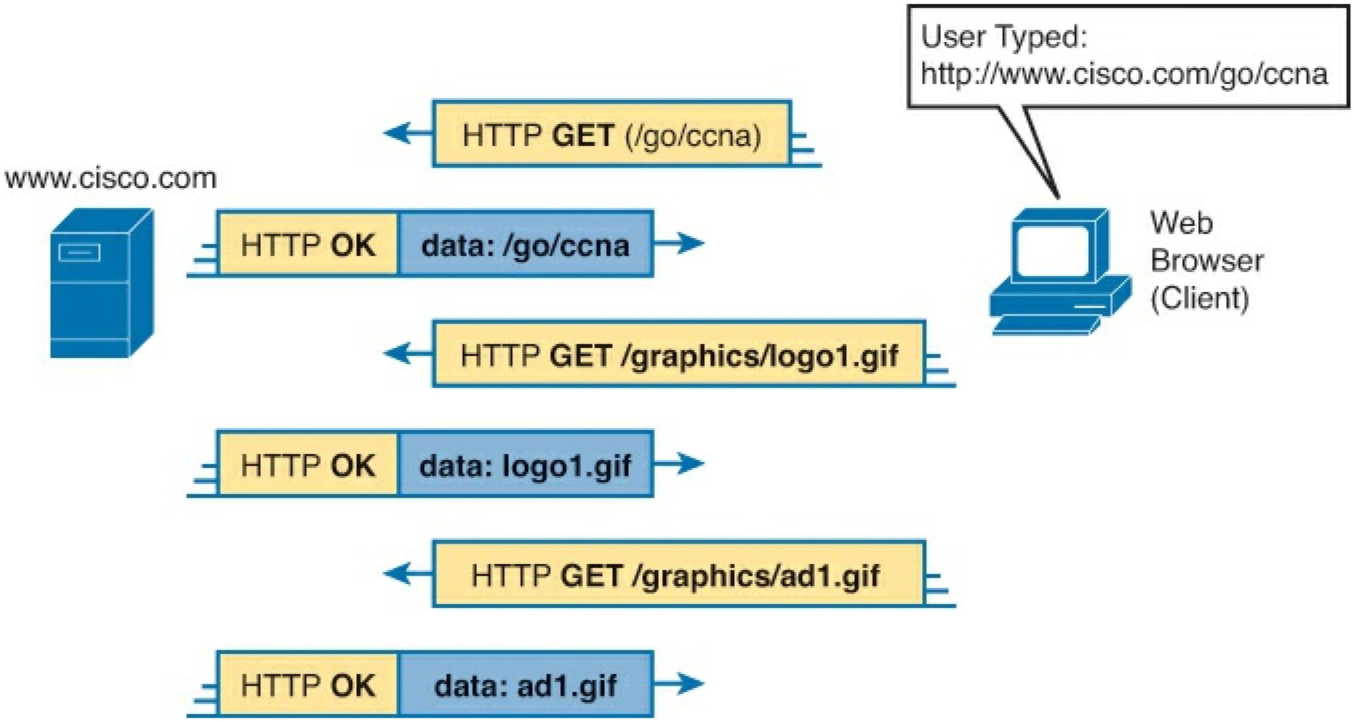


Figure 5-10. Multiple HTTP Get Requests/Responses

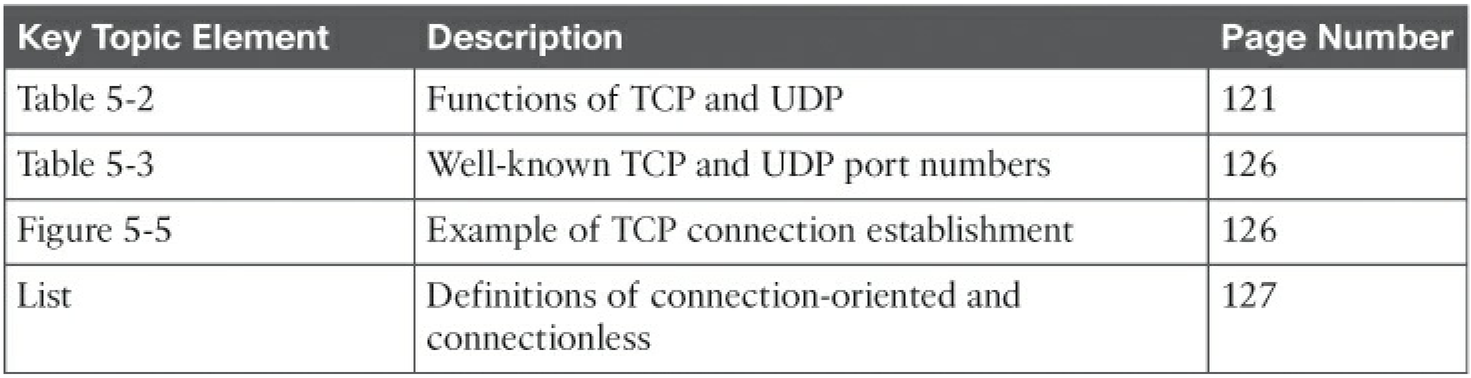
In this case, after the web browser gets the first file—the one called "*go*ccna" in the URL—the browser reads and interprets that file. Besides containing parts of the web page, the file refers to two other files, so the browser issues two additional HTTP get requests. Note that, even though it isn't shown in the figure, all these commands flow over one (or possibly more) TCP connections between the client and the server. This means that TCP would provide error recovery, ensuring that the data was delivered.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 5-5 lists these key topics and where each is discussed.

Table 5-5. Key Topics for Chapter 5



Key Topic Element	Description	Page Number
Table 5-2	Functions of TCP and UDP	121
Table 5-3	Well-known TCP and UDP port numbers	126
Figure 5-5	Example of TCP connection establishment	126
List	Definitions of connection-oriented and connectionless	127

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists for you to check your work.

Definitions of Key Terms

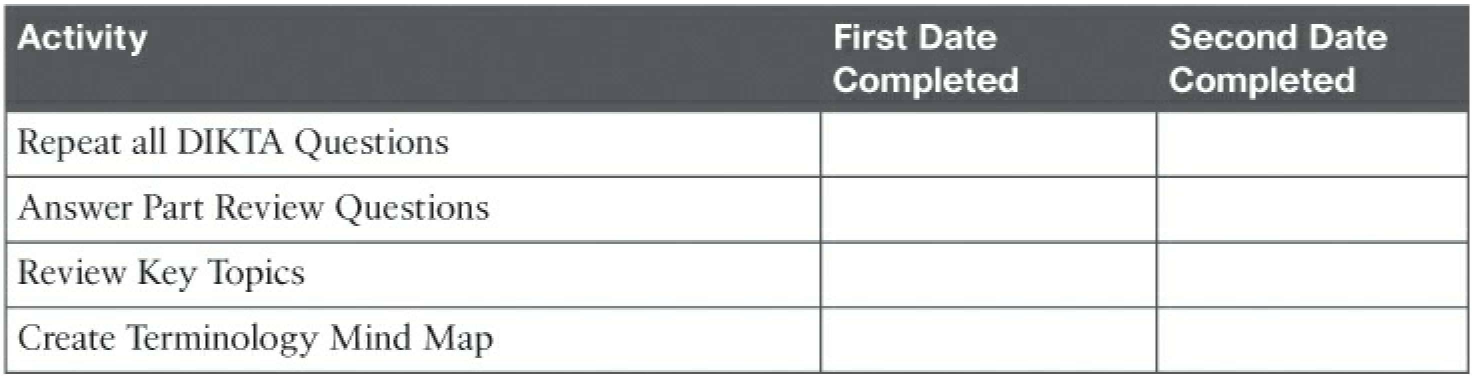
After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

connection establishment
error detection
error recovery
flow control
forward acknowledgment
HTTP
ordered data transfer
port
segment
sliding windows
URL
VoIP
web server

Part I Review

Keep track of your part review progress with the checklist shown in Table P1-1. Details on each task follow the table.

Table P1-1. Part I Review Checklist



Activity	First Date Completed	Second Date Completed
Repeat all DIKTA Questions		
Answer Part Review Questions		
Review Key Topics		
Create Terminology Mind Map		

Repeat All DIKTA Questions

For this task, answer the "Do I Know This Already?" questions again for the chapters in this part of the book, using the PCPT software. Refer to the Introduction to this book, heading "How to View Only DIKTA Questions by Part," for help with how to make the PCPT software show you DIKTA questions for this part only.

Answer Part Review Questions

For this task, answer the Part Review questions for this part of the book, using the PCPT software. Refer to the Introduction to this book, heading "How to View Only Part Review Questions by Part," for help with how to make the PCPT software show you Part Review questions for this part only.

Review Key Topics

Key Topic

Browse back through the chapters, and look for the Key Topic icons. If you do not remember some details, take the time to reread those topics.

Create Terminology Mind Maps

The first part of this book introduces a large amount of terminology. The sheer number of terms can be overwhelming. But more and more, while you work through each new chapter, you will become more comfortable with the terms. And the better you can remember the core meaning of a term, the easier your reading will be going forward.

For your first mind map exercise in this book, without looking back at the chapters or your notes, you will create six mind maps. The mind maps will each list a number in the center, 1 through 6, to match the numbers shown in Figure P1-1. Your job is as follows:

- Think of every term that you can remember from Part I of the book.
- Think of each of the six mind maps as being about the item next to the number in Figure P1-1. For example, number 1 is about the user PC, number 2 is about an Ethernet cable that connects PC1 to a switch, and so on.
- Add each term that you can recall to all mind maps to which it applies. For example, "leased line" would apply to mind map number 5.
- If a term seems to apply to multiple places, add it to all those mind maps.
- After you have written every term you can remember into one of the mind maps, review the Key Topics lists at the end of Chapters 1 through 5. Add any terms you forgot to your mind maps.

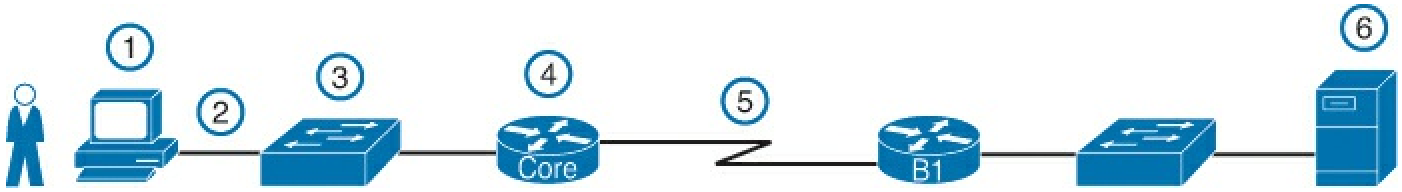


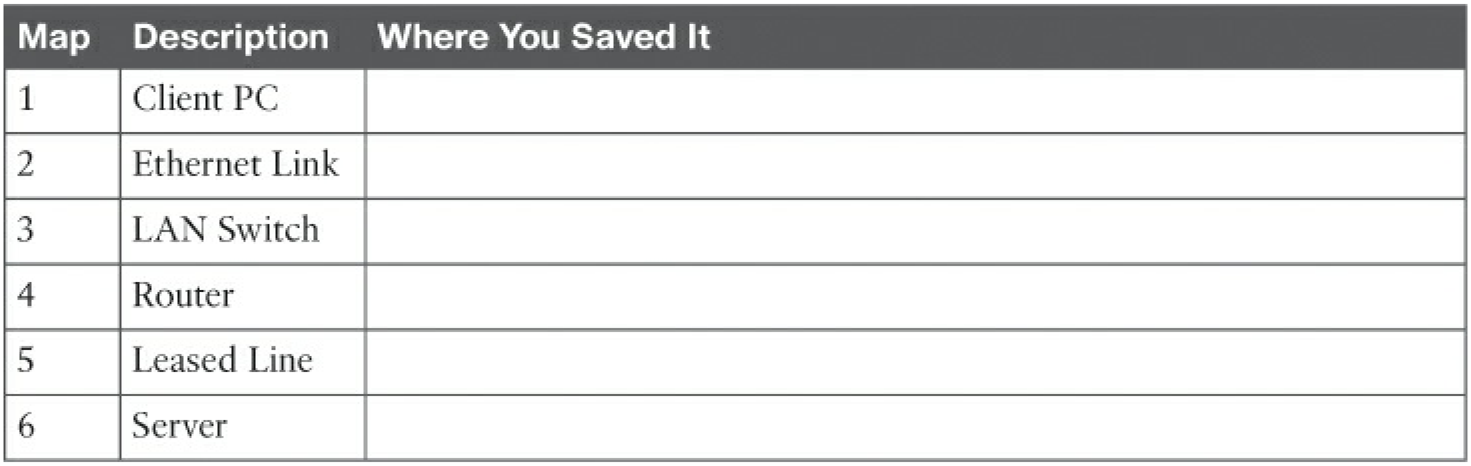
Figure P1-1. Sample Network to Use with Mind Map Exercise

The goal of these minds maps is to help you recall the terms with enough meaning to associate the terms with the right part of a simple network design. On your first review of Part I, do not be concerned if you cannot fully explain each term, because you will learn many of these terms more fully just by reading the rest of the book.

> **Note**
>
> For more information on mind mapping, refer to the Introduction, in the section "About Mind Maps."

Create the mind maps in Table P1-2 on paper, using any mind-mapping software, or even any drawing application. If you use an application, note the filename and location where you saved the file, for later reference. Sample answers are listed in DVD Appendix O, "Mind Map Solutions."

Table P1-2. Configuration Mind Maps for Part I Review



Map	Description	Where You Saved It
1	Client PC	
2	Ethernet Link	
3	LAN Switch	
4	Router	
5	Leased Line	
6	Server	

Part II: Ethernet LANs and Switches

Part II discusses how to build a small-to medium-sized Ethernet LAN today. Chapter 6 completes the discussion of Ethernet LAN concepts, building on the introduction to LANs found in Chapter 2. Chapters 7 and 8 unravel how Cisco switches work, first looking at administrative settings, and then discussing settings that impact how the switch forwards Ethernet frames. Chapter 9 moves on to discuss virtual LANs (VLAN), a widely used tool to use one set of switches to create many different LANs. Finally, Chapter 10 discusses how to troubleshoot Ethernet LANs.

Chapter 6: Building Ethernet LANs with Switches

Chapter 7: Installing and Operating Cisco LAN Switches

Chapter 8: Configuring Ethernet Switching

Chapter 9: Implementing Ethernet Virtual LANs

Chapter 10: Troubleshooting Ethernet LANs

Part II Review

Chapter 6. Building Ethernet LANs with Switches

This chapter covers the following exam topics:

Operation of IP Data Networks

- Recognize the purpose and functions of various network devices such as Routers, Switches, Bridges and Hubs.
- Select the components required to meet a given network specification.
- Predict the data flow between two hosts across a network.
- Identify the appropriate media, cables, ports, and connectors to connect Cisco network devices to other network devices and hosts in a LAN

LAN Switching Technologies

- Determine the technology and media access control method for Ethernet networks
- Identify basic switching concepts and the operation of Cisco switches.
    - Collision Domains
    - Broadcast Domains
    - Types of switching
    - CAM Table

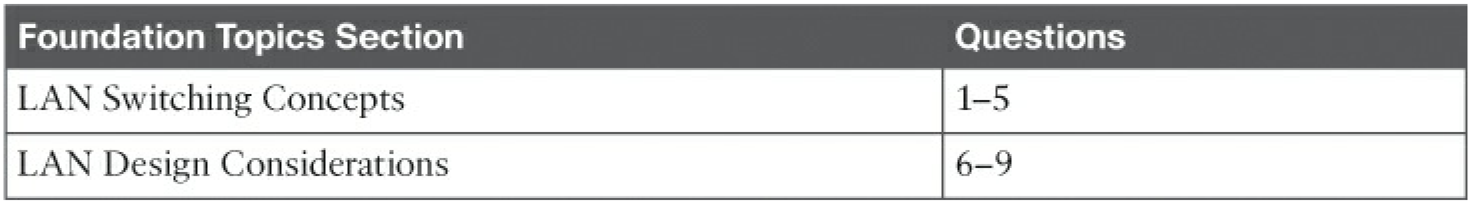
While Ethernet defines what happens on each Ethernet link, the more interesting and more detailed work happens on the devices connected to those links: the NICs inside devices and the LAN switches. This chapter takes the Ethernet LAN basics introduced in Chapter 2, "Fundamentals of Ethernet LANs," and dives deeply into many aspects of a modern Ethernet LAN, while focusing on the primary device used to create these LANs: LAN switches.

This chapter breaks down the discussion of Ethernet and LAN switching into two sections. The first major section looks at the logic used by LAN switches when forwarding Ethernet frames, along with the related terminology. The second section considers design and implementation issues, as if you were building a new Ethernet LAN in a building or campus. This second section considers design issues, including using switches for different purposes, when to choose different types of Ethernet links, and how to take advantage of Ethernet autonegotiation.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 6-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
LAN Switching Concepts	1–5
LAN Design Considerations	6–9

1. Which of the following statements describes part of the process of how a switch decides to forward a frame destined for a known unicast MAC address?
    - **a.** It compares the unicast destination address to the bridging, or MAC address, table.
    - **b.** It compares the unicast source address to the bridging, or MAC address, table.
    - **c.** It forwards the frame out all interfaces in the same VLAN except for the incoming interface.
    - **d.** It compares the destination IP address to the destination MAC address.
    - **e.** It compares the frame's incoming interface to the source MAC entry in the MAC address table.
2. Which of the following statements describes part of the process of how a LAN switch decides to forward a frame destined for a broadcast MAC address?
    - **a.** It compares the unicast destination address to the bridging, or MAC address, table.
    - **b.** It compares the unicast source address to the bridging, or MAC address, table.
    - **c.** It forwards the frame out all interfaces in the same VLAN except for the incoming interface.
    - **d.** It compares the destination IP address to the destination MAC address.
    - **e.** It compares the frame's incoming interface to the source MAC entry in the MAC address table.
3. Which of the following statements best describes what a switch does with a frame destined for an unknown unicast address?
    - **a.** It forwards out all interfaces in the same VLAN except for the incoming interface.
    - **b.** It forwards the frame out the one interface identified by the matching entry in the MAC address table.

c. It compares the destination IP address to the destination MAC address.

d. It compares the frame’s incoming interface to the source MAC entry in the MAC address table.

4. Which of the following comparisons does a switch make when deciding whether a new MAC address should be added to its MAC address table?

a. It compares the unicast destination address to the bridging, or MAC address, table.

b. It compares the unicast source address to the bridging, or MAC address, table.

c. It compares the VLAN ID to the bridging, or MAC address, table.

d. It compares the destination IP address’s ARP cache entry to the bridging, or MAC address, table.

5. PC1, with MAC address 1111.1111.1111, is connected to Switch SW1’s Fa0/1 interface. PC2, with MAC address 2222.2222.2222, is connected to SW1’s Fa0/2 interface. PC3, with MAC address 3333.3333.3333, connects to SW1’s Fa0/3 interface. The switch begins with no dynamically learned MAC addresses, followed by PC1 sending a frame with a destination address of 2222.2222.2222. If the next frame to reach the switch is a frame sent by PC3, destined for PC2’s MAC address of 2222.2222.2222, which of the following are true? (Choose two answers.)

a. The switch forwards the frame out interface Fa0/1.

b. The switch forwards the frame out interface Fa0/2.

c. The switch forwards the frame out interface Fa0/3.

d. The switch discards (filters) the frame.

6. Which of the following devices would be in the same collision domain as PC1?

a. PC2, which is separated from PC1 by an Ethernet hub

b. PC3, which is separated from PC1 by a transparent bridge

c. PC4, which is separated from PC1 by an Ethernet switch

d. PC5, which is separated from PC1 by a router

7. Which of the following devices would be in the same broadcast domain as PC1? (Choose three answers.)

a. PC2, which is separated from PC1 by an Ethernet hub

b. PC3, which is separated from PC1 by a transparent bridge

c. PC4, which is separated from PC1 by an Ethernet switch

d. PC5, which is separated from PC1 by a router

8. Which of the following Ethernet standards support a maximum cable length of longer than 100 meters? (Choose two answers.)

a. 100BASE-T

b. 1000BASE-LX

c. 1000BASE-T

d. 100BASE-FX

9. A Cisco LAN switch connects to three PCs (PC1, PC2, and PC3), each directly using a cable that supports Ethernet UTP speeds up through 1000 Mbps (1 Gbps). PC1 uses a NIC that supports only 10BASE-T, while PC2 has a 10/100 NIC, and PC3 has a 10/100/1000 NIC. Assuming that the PCs and switch use IEEE autonegotiation, which PCs will use half-duplex?

a. PC1

b. PC2

c. PC3

d. None of the PCs will use half-duplex.

Answers to the “Do I Know This Already?” quiz:

1 A 2 C 3 A 4 B 5 A and B 6 A 7 A, B, and C 8 B and D 9 D

Foundation Topics

LAN Switching Concepts

Ethernet switches receive Ethernet frames in one port and then forward (switch) the frames out one (or more) other port. This first major section focuses on how switches make these switching decisions. Along the way, this section discusses several related concepts that you need to know to have a more complete understanding of how switches forward Ethernet frames.

In particular, this section first discusses some older Ethernet LANs, using hubs, so that some current terminology makes more sense. The bulk of this section focuses on the core switch forwarding logic and ends with a short discussion of some options for how switches from Cisco Systems process Ethernet frames internally.

Historical Progression: Hubs, Bridges, and Switches

First, think back to the first UTP-based Ethernet standard, 10BASE-T, introduced in 1990. 10BASE-T used a centralized cabling model similar to today's Ethernet LANs, with each device connecting to the LAN using a UTP cable. However, instead of a LAN switch, the early 10BASE-T networks used hubs, because LAN switches had not yet been created. Figure 6-1 depicts the typical topology for 10BASE-T with a hub.

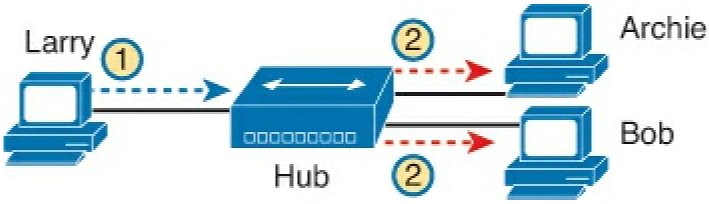


Figure 6-1. 10BASE-T (with a Hub)

Although using 10BASE-T with a hub improved Ethernet as compared to the older standards, several drawbacks continued to exist, even with 10BASE-T using hubs:

- When hubs receive an electrical signal in one port (step 1 in Figure 6-1), the hub repeats the signal out all other ports (step 2 in the figure).
- When two or more devices send at the same time, an electrical collision occurs, making both signals corrupt.
- As a result, devices must take turns by using carrier sense multiple access with collision detection (CSMA/CD) logic, so the devices share the (10-Mbps) bandwidth.
- Broadcasts sent by one device are heard by, and processed by, all other devices on the LAN.
- Unicast frames are heard by all other devices on the LAN.

Over time, the performance of many Ethernet networks based on hubs started to degrade. People developed applications to take advantage of the LAN bandwidth. More devices were added to each Ethernet. However, the devices on the same Ethernet could not send (collectively) more than 10 Mbps of traffic because they all shared the 10 Mbps of bandwidth. In addition, the increase in traffic volumes resulted in an increased number of collisions, requiring more retransmissions and wasting more LAN capacity.

Ethernet transparent bridges, or simply bridges, helped solve this performance problem with 10BASE-T. After they were added to a 10BASE-T LAN, the following improvements were made:

- Bridges separated devices into groups called *collision domains*.
- Bridges reduced the number of collisions that occurred in the network, because frames inside one collision domain did not collide with frames in another collision domain.
- Bridges increased bandwidth by giving each collision domain its own separate bandwidth, with one sender at a time per collision domain.

Figure 6-2 shows the effect of migrating from using a 10BASE-T hub without a bridge (as in Figure 6-1) to a network that uses a bridge. The bridge in this case separates the network into two separate collision domains (CD).

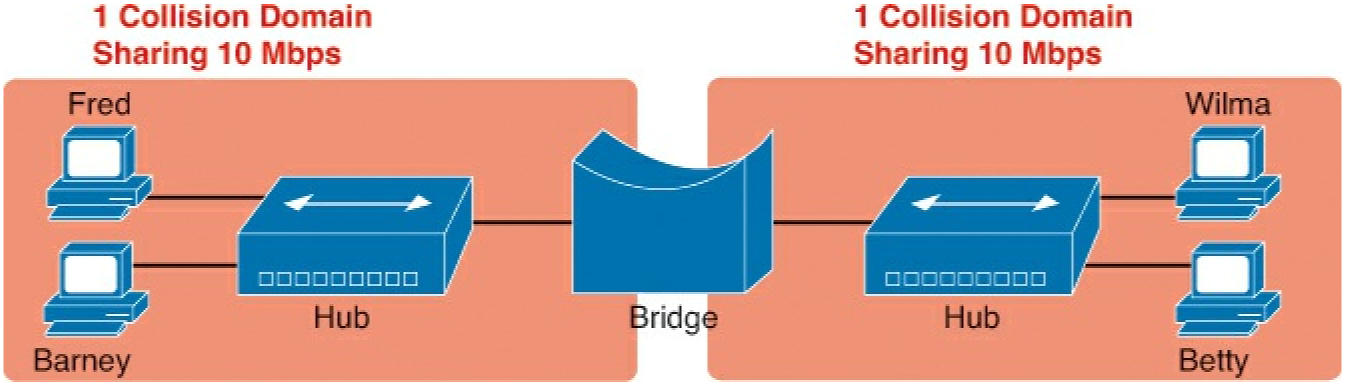


Figure 6-2. Bridge Creates Two Collision Domains and Two Shared Ethernets

The bridge, a predecessor to today's Ethernet LAN switch, uses logic so that the frames in one CD do not collide with frames in the other CD. The bridge forwards frames between its two interfaces, and unlike a hub, a bridge will buffer or queue the frame until the outgoing interface can send the frame. For example, Fred and Betty can both send a frame to Barney at the same time, and the bridge will queue the frame sent by Betty, waiting to forward it to the CD on the left, until the CD on the left is not busy.

Adding the bridge in Figure 6-2 really creates two separate 10BASE-T networks—one on the left and one on the right. The 10BASE-T network on the left has its own 10 Mbps to share, as does the network on the right. So, in this example, the total network bandwidth is doubled to 20 Mbps as compared with the 10BASE-T network in Figure 6-1, because devices on each side of the network can send at 10 Mbps at the same time.

LAN switches perform the same basic core functions as bridges, but at much faster speeds and with many enhanced features. Like bridges, switches segment a LAN into separate collision domains, each with its own capacity. And if the network does not have a hub, each single link is considered its own CD, even if no collisions can actually occur in that case.

For example, Figure 6-3 shows a simple LAN with a switch and four PCs. The switch creates four CDs, with the ability to send at 100 Mbps in this case on each of the four links. And with no hubs, each link can run at full-duplex, doubling the capacity of each link.

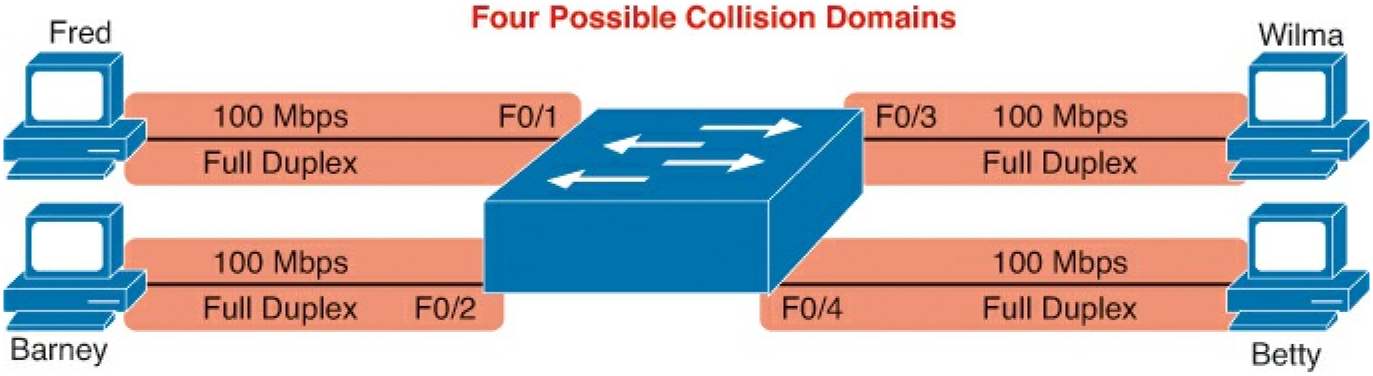


Figure 6-3. Switch Creates Four Collision Domains and Four Ethernet Segments

Switching Logic

Ultimately, the role of a LAN switch is to forward Ethernet frames. To achieve that goal, switches use logic—logic based on the source and destination MAC address in each frame's Ethernet header.

This book discusses how switches forward unicast frames and broadcast frames, ignoring multicast Ethernet frames. Unicast frames have a unicast address as a destination; these addresses represent a single device. A broadcast frame has a destination MAC address of FFFF.FFFF.FFFF; this frame should be delivered to all devices on the LAN.

LAN switches receive Ethernet frames and then make a switching decision: either forward the frame out some other port(s) or ignore the frame. To accomplish this primary mission, transparent bridges perform three actions:

Key Topic

1. Deciding when to forward a frame or when to filter (not forward) a frame, based on the destination MAC address.
2. Learning MAC addresses by examining the source MAC address of each frame received by the switch.
3. Creating a (Layer 2) loop-free environment with other bridges by using Spanning Tree Protocol (STP).

The first action is the switch's primary job, whereas the other two items are overhead functions. The next sections examine each of these steps in order.

> **Note**
>
> Throughout this book's discussion of LAN switches, the terms *switch port* and *switch interface* are synonymous.

The Forward-Versus-Filter Decision

To decide whether to forward a frame, a switch uses a dynamically built table that lists MAC addresses and outgoing interfaces. Switches compare the frame's destination MAC address to this table to decide whether the switch should forward a frame or simply ignore it. For example, consider the simple network shown in Figure 6-4, with Fred sending a frame to Barney.

Key Topic

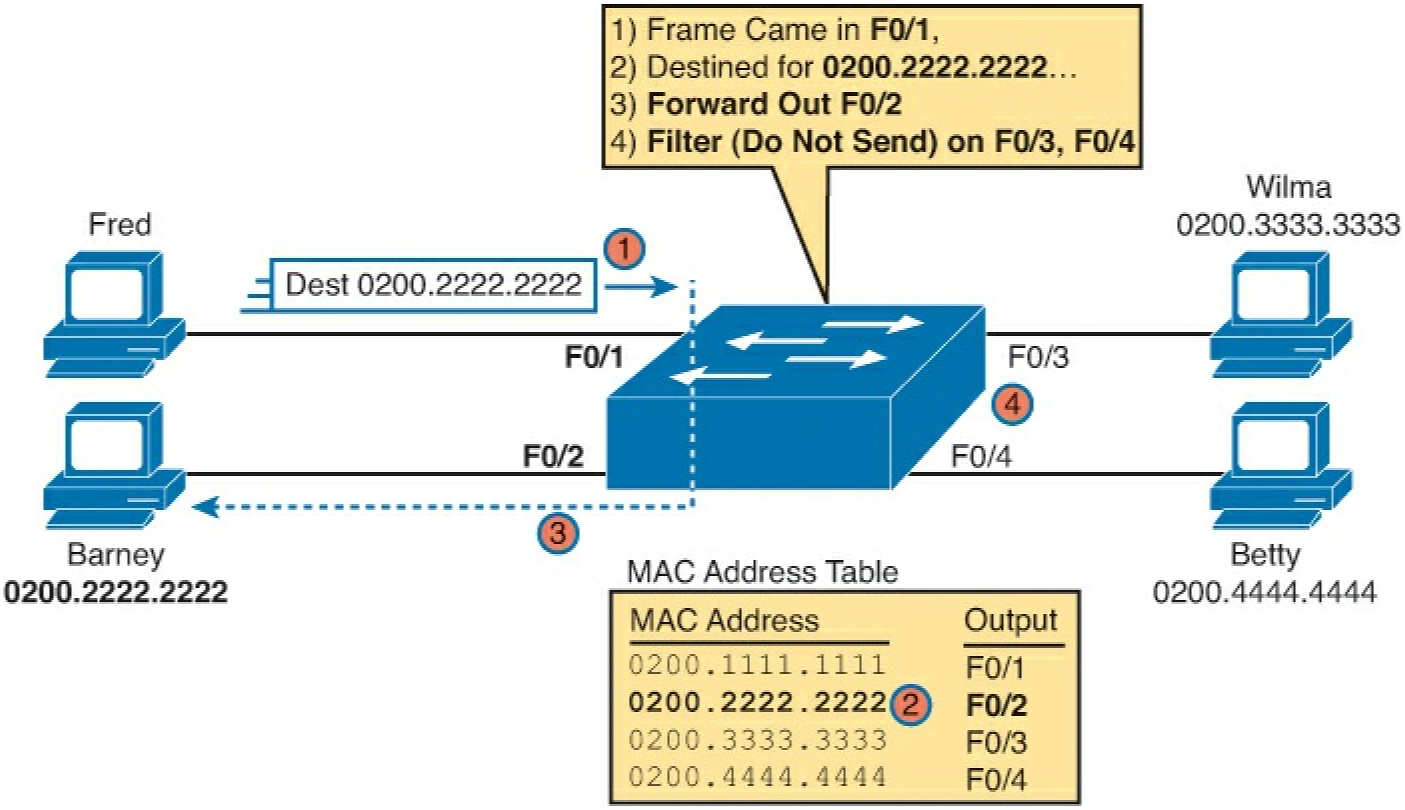

1) Frame Came in F0/1,
2) Destined for 0200.2222.2222…
3) Forward Out F0/2
4) Filter (Do Not Send) on F0/3, F0/4
Fred
Dest 0200.2222.2222
①
F0/1
F0/2
③
Barney
0200.2222.2222
Wilma
0200.3333.3333
F0/3
④
F0/4
Betty
0200.4444.4444
MAC Address Table
MAC Address
Output
0200.1111.1111
F0/1
0200.2222.2222
②
F0/2
0200.3333.3333
F0/3
0200.4444.4444
F0/4

Figure 6-4. Sample Switch Forwarding and Filtering Decision

In this figure, Fred sends a frame with destination address 0200.2222.2222 (Barney's MAC address). The switch compares the destination MAC address (0200.2222.2222) to the MAC address table, matching the bold table entry. That matched table entry tells the switch to forward the frame out port F0/2, and only port F0/2.

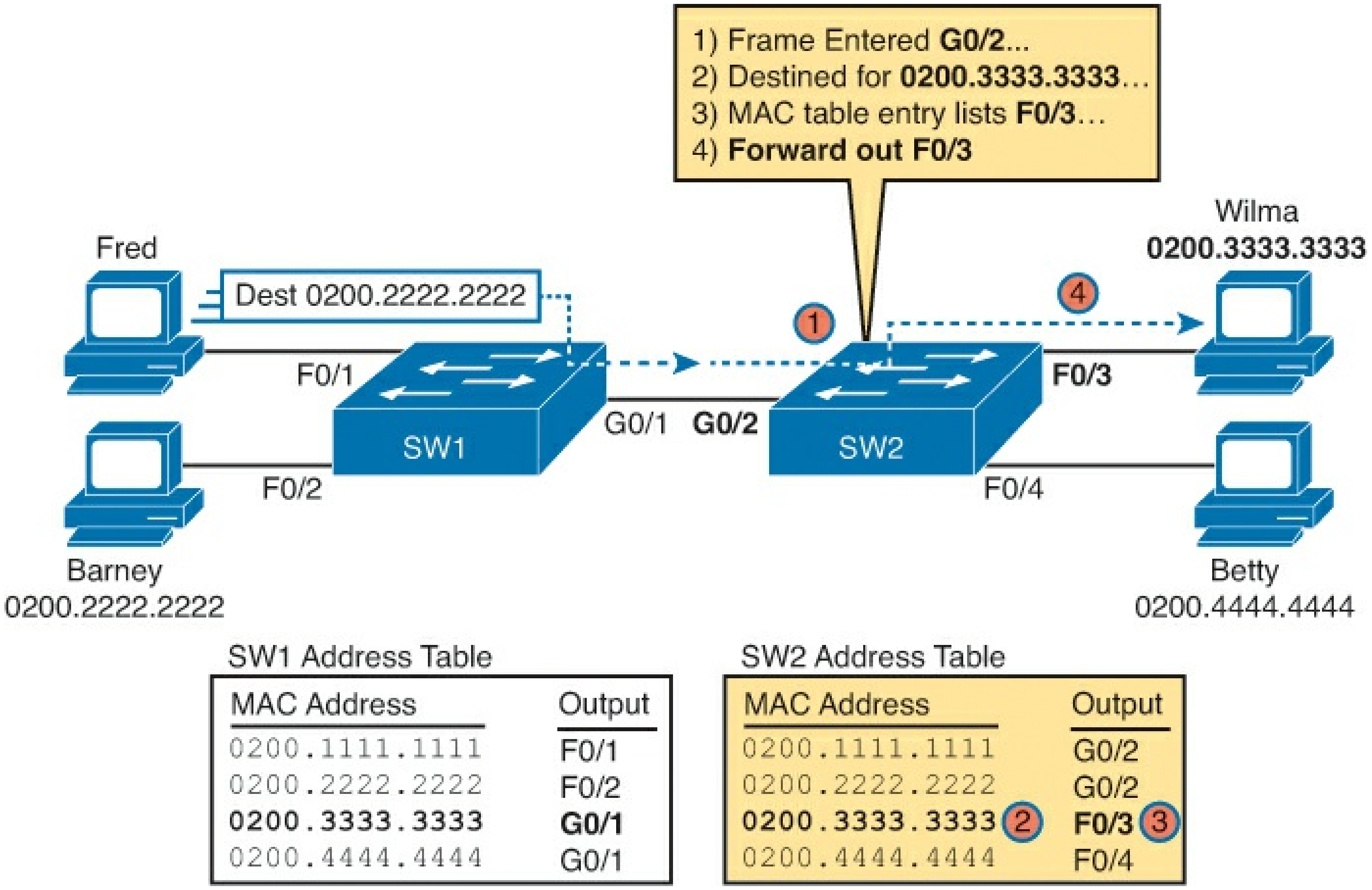
Note

A switch's MAC address table is also called the *switching table*, or *bridging table*, or even the *Content Addressable Memory (CAM)* table, in reference to the type of physical memory used to store the table.

A switch's MAC address table lists the location of each MAC relative to that one switch. In LANs with multiple switches, each switch makes an independent forwarding decision based on its own MAC address table. Together, they forward the frame so that it eventually arrives at the destination.

For example, Figure 6-5 shows the same four PCs as in Figure 6-4, but now with two LAN switches. In this case, Fred sends a frame to Wilma, with destination MAC 0200.3333.3333. Switch SW1 sends the frame out its G0/1 port, per SW1's MAC address table. Then at Step 2, switch SW2 forwards the frame out its F0/3 port, based on SW2's MAC address table.

Key Topic


1) Frame Entered G0/2...
2) Destined for 0200.3333.3333...
3) MAC table entry lists F0/3...
4) Forward out F0/3
Fred
Dest 0200.2222.2222
F0/1
F0/2
SW1
G0/1
G0/2
SW2
F0/3
F0/4
Wilma
0200.3333.3333
Barney
0200.2222.2222
Betty
0200.4444.4444
1
2
3
4

SW1 Address Table

MAC Address	Output
0200.1111.1111	F0/1
0200.2222.2222	F0/2
0200.3333.3333	**G0/1**
0200.4444.4444	G0/1

SW2 Address Table

MAC Address	Output
0200.1111.1111	G0/2
0200.2222.2222	G0/2
0200.3333.3333 ②	**F0/3** ③
0200.4444.4444	F0/4

Figure 6-5. Forwarding Decision with Two Switches

> **Note**
>
> The forwarding choice by a switch was formerly called a *forward-versus-filter* decision, because the switch also chooses to not forward (to filter) frames, not sending the frame out some ports.

How Switches Learn MAC Addresses

The second main function of a switch is to learn the MAC addresses and interfaces to put into its address table. With a full and accurate MAC address table, the switch can make accurate forwarding and filtering decisions.

Switches build the address table by listening to incoming frames and examining the *source MAC address* in the frame. If a frame enters the switch and the source MAC address is not in the MAC address table, the switch creates an entry in the table. That table entry lists the interface from which the frame arrived. Switch learning logic is that simple.

Figure 6-6 depicts the same network as Figure 6-4, but before the switch has built any address table entries. The figure shows the first two frames sent in this network—first a frame from Fred, addressed to Barney, and then Barney's response, addressed to Fred.

Key Topic

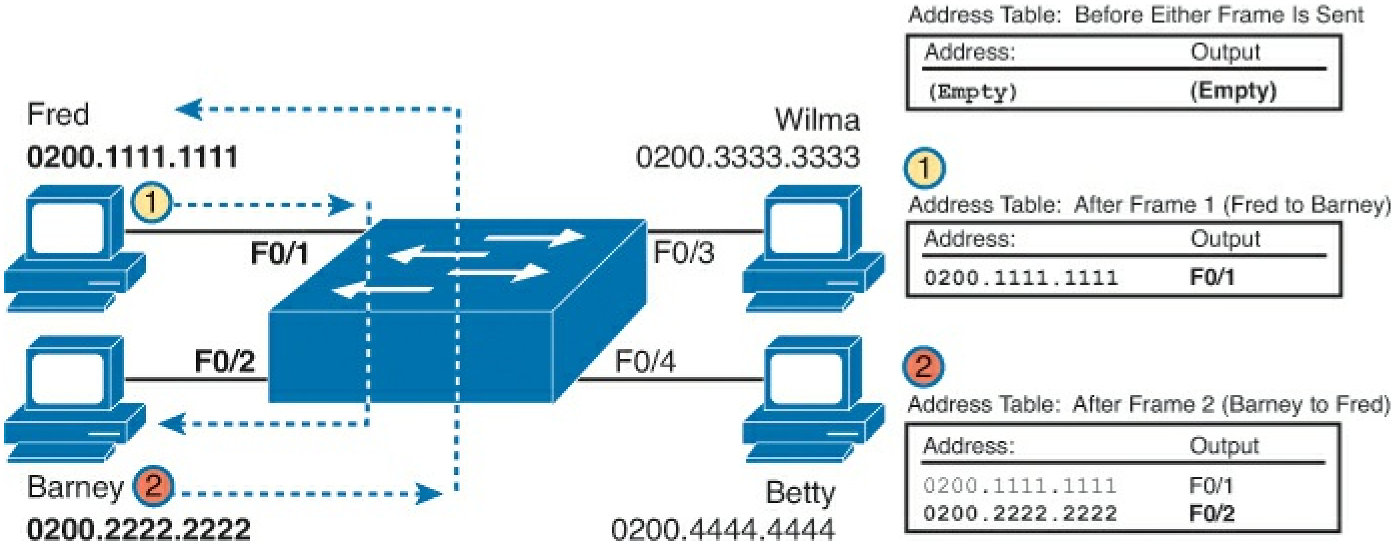


Figure 6-6. Switch Learning: Empty Table and Adding Two Entries

As shown in the figure, after Fred sends his first frame (labeled "1") to Barney, the switch adds an entry for 0200.1111.1111, Fred's MAC address, associated with interface F0/1. When Barney replies in Step 2, the switch adds a second entry, this one for 0200.2222.2222, Barney's MAC address, along with interface F0/2, which is the interface in which the switch received the frame. Learning always occurs by looking at the source MAC address in the frame.

Switches keep a timer for each entry in the MAC address table, called an *inactivity timer*. The switch sets the timer to 0 for new entries. Each time the switch receives another frame with that same source MAC address, the timer is reset to 0. The timer counts upward, so the switch can tell which entries have gone the longest time since receiving a frame from that device. The switch then removes entries from the table when they become old. Or, if the switch ever runs out of space for entries in the MAC address table, the switch can then remove table entries with the oldest (largest) inactivity timers.

Flooding Frames

Now again turn your attention to the forwarding process, using Figure 6-6. What do you suppose the switch does with Fred's first frame in Figure 6-6, the one that occurred when there were no entries in the MAC address table? As it turns out, when there is no matching entry in the table, switches forward the frame out all interfaces (except the incoming interface) using a process called *flooding*.

Switches flood *unknown unicast frames* (frames whose destination MAC addresses are not yet in the address table). Flooding means that the switch forwards copies of the frame out all ports, except the port on which the frame was received. If the unknown device receives the frame and sends a reply, the reply frame's source MAC address will allow the switch to build a correct MAC table entry for that device.

Switches also forward LAN broadcast frames, because this process helps deliver a copy of the frame to all devices in the LAN.

For example, Figure 6-6 shows the first frame, sent to Barney's MAC address, just going to Barney. However, in reality, the switch floods this frame out F0/2, F0/3, and F0/4, even though 0200.2222.2222 (Barney) is only off F0/2. The switch does not forward the frame back out F0/1, because a switch never forwards a frame out the same interface on which it arrived.

Avoiding Loops Using Spanning Tree Protocol

The third primary feature of LAN switches is loop prevention, as implemented by *Spanning Tree Protocol (STP)*. Without STP, any flooded frames would loop for an indefinite period of time in Ethernet networks with physically redundant links. To prevent looping frames, STP blocks some ports from forwarding frames so that only one active path exists between any pair of LAN segments.

The result of STP is good: Frames do not loop infinitely, which makes the LAN usable. However, STP has negative features as well, including the fact that it takes some work to balance traffic across the redundant alternate links.

A simple example makes the need for STP more obvious. Remember, switches flood frames sent to both unknown unicast MAC addresses and broadcast addresses. Figure 6-7 shows an unknown unicast frame, sent by Larry to Bob, which loops forever because the network has redundancy but no STP.

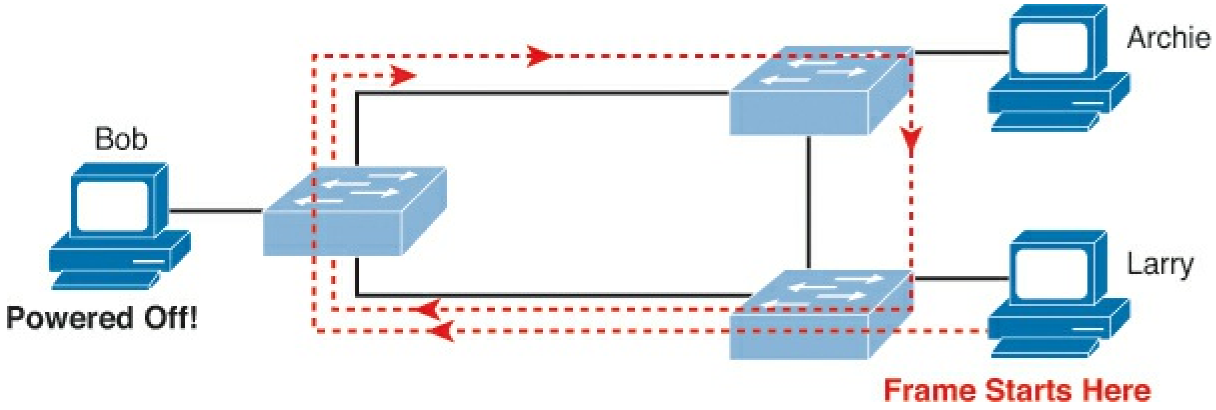


Figure 6-7. Network with Redundant Links but Without STP: The Frame Loops Forever

Because none of the switches list Bob's MAC address in their address tables, each switch floods the frame. A physical loop exists through the three switches. The switches keep forwarding the frame out all ports, and copies of the frame go around and around.

To avoid Layer 2 loops, all switches need to use STP. STP causes each interface on a switch to settle into either a blocking state or a forwarding state. *Blocking* means that the interface cannot forward or receive data frames, while *forwarding* means that the interface can send and receive data frames. If a correct subset of the interfaces is blocked, only a single currently active logical path exists between each pair of LANs.

> **Note**
>
> STP behaves identically for a transparent bridge and a switch. Therefore, the terms *bridge*, *switch*, and *bridging device* all are used interchangeably when discussing STP.

Chapters 1 and 2 in the *Cisco CCNA Routing and Switching ICND2 200-101 Official Cert Guide* cover the details of how STP prevents loops.

Internal Processing on Cisco Switches

This chapter has already explained how switches decide whether to forward or filter a frame. As soon as a Cisco switch decides to forward a frame, the switch can use a couple of different types of internal processing variations. Almost all of the more recently released switches use store-and-forward processing, but all three types of these internal processing methods are supported in at least one type of Cisco switch.

Some switches, and transparent bridges in general, use *store-and-forward processing*. With store-and-forward, the switch must receive the entire frame before forwarding the first bit of the frame. However, Cisco also offers two other internal processing methods for switches: *cut-through* and *fragment-free*. Because the destination MAC address occurs very early in the Ethernet header, a switch can make a forwarding decision long before the switch has received all the bits in the frame. The cut-through and fragment-free processing methods allow the switch to start forwarding the frame before the entire frame has been received, reducing time required to send the frame (the latency, or delay).

With *cut-through* processing, the switch starts sending the frame out the output port as soon as possible. Although this might reduce latency, it also propagates errors. Because the Frame Check Sequence (FCS) is in the Ethernet trailer, the switch cannot determine whether the frame had any errors before starting to forward the frame. So, the switch reduces the frame's latency, but with the price of having forwarded some frames that contain errors.

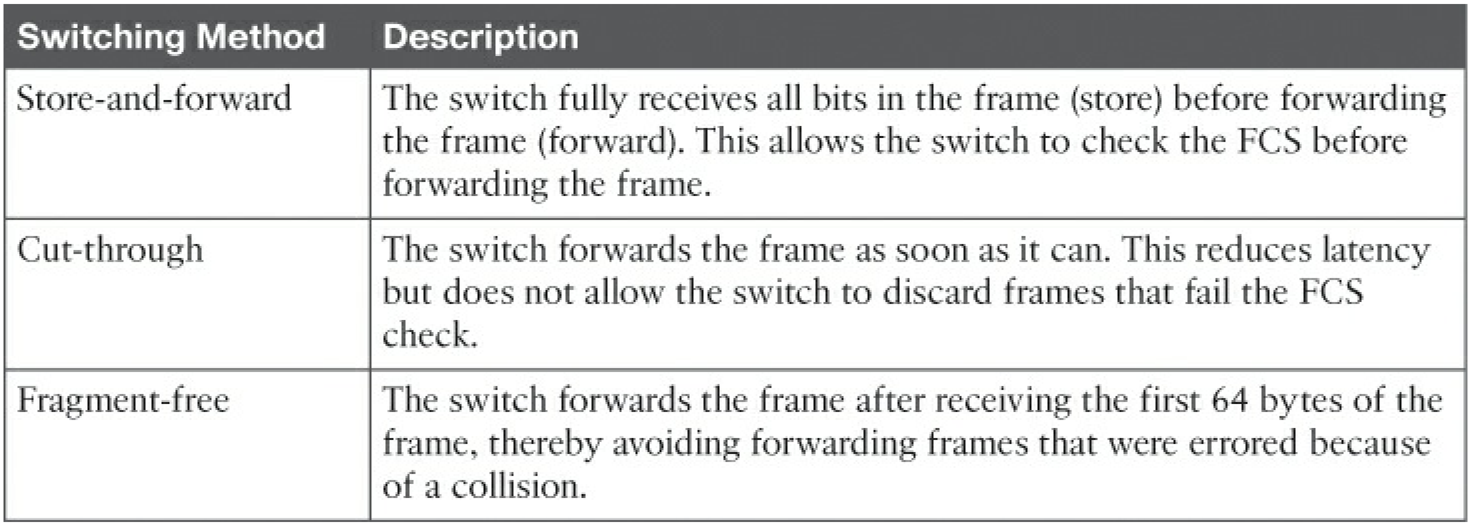
Fragment-free processing works similarly to cut-through, but it tries to reduce the number of errored frames that it forwards. One interesting fact about Ethernet CSMA/CD logic is that collisions should be detected within the first 64 bytes of a frame. Fragment-free processing works like cut-through logic, but it waits to receive the first 64 bytes before forwarding a frame. The frames experience less latency than with store-and-forward logic and slightly more latency than with cut-through, but frames that have errors as a result of collisions are not forwarded.

With many links to the desktop running at 100 Mbps, uplinks at 1 Gbps, and faster application-specific integrated circuits (ASIC), today's switches typically use store-and-forward processing, because the improved latency of the other two switching methods is negligible at these speeds.

The internal processing algorithms used by switches vary among models and vendors; regardless, the internal processing can be categorized as one of the methods listed in Table 6-2.

Key Topic

Table 6-2. Switch Internal Processing



Switching Method	Description
Store-and-forward	The switch fully receives all bits in the frame (store) before forwarding the frame (forward). This allows the switch to check the FCS before forwarding the frame.
Cut-through	The switch forwards the frame as soon as it can. This reduces latency but does not allow the switch to discard frames that fail the FCS check.
Fragment-free	The switch forwards the frame after receiving the first 64 bytes of the frame, thereby avoiding forwarding frames that were errored because of a collision.

LAN Switching Summary

Switches provide many additional features not offered by older LAN devices such as hubs and bridges. In particular, LAN switches provide the following benefits:

Key Topic

- Switch ports connected to a single device microsegment the LAN, providing dedicated bandwidth to that single device.
- Switches allow multiple simultaneous conversations between devices on different ports.
- Switch ports connected to a single device support full-duplex, in effect doubling the amount of bandwidth available to the device.
- Switches support rate adaptation, which means that devices that use different Ethernet speeds can communicate through the switch (hubs cannot).

Switches use Layer 2 logic, examining the Ethernet data link header to choose how to process frames. In particular, switches make decisions to forward and filter frames, learn MAC addresses, and use STP to avoid loops, as follows:

Key Topic

Step 1. Switches forward frames based on the destination address:

- **A.** If the destination address is a broadcast, multicast, or unknown destination unicast (a unicast not listed in the MAC table), the switch floods the frame.
- **B.** If the destination address is a known unicast address (a unicast address found in the MAC table):
    - **i.** If the outgoing interface listed in the MAC address table is different from the interface in which the frame was received, the switch forwards the frame out the outgoing interface.
    - **ii.** If the outgoing interface is the same as the interface in which the frame was received, the switch filters the frame, meaning that the switch simply ignores the frame and does not forward it.

Step 2. Switches use the following logic to learn MAC address table entries:

- **A.** For each received frame, examine the source MAC address and note the interface from which the frame was received.
- **B.** If it is not already in the table, add the MAC address and interface it was learned on, setting the inactivity timer to 0.
- **C.** If it is already in the table, reset the inactivity timer for the entry to 0.

Step 3. Switches use STP to prevent loops by causing some interfaces to block, meaning that they do not send or receive frames.

Design Choices in Ethernet LANs

The first of the two major sections of this chapter explained the details of how LAN switches work. The second major section now examines a variety of topics related to LAN design.

This section moves around between many different topics. The first topic explains the concept of collision domains as compared to broadcast domains, both of which impact LAN performance. These two topics give you enough background to then understand the most commonly used tool mentioned in this section: virtual LANs (VLAN). Then this section examines some Ethernet LAN design issues, and closes with how to more easily migrate Ethernet LANs over time to use the latest standards by using autonegotiation.

Collision Domains, Broadcast Domains, and VLANs

When creating any Ethernet LAN today, you use LAN switches and routers. You also have to think about older legacy devices like hubs and bridges, just in case some still exist. The different parts of an Ethernet LAN can behave differently, in terms of function and performance, depending on which types of devices are used. These differences then affect a network engineer's decision when choosing how to design a LAN.

The terms *collision domain* and broadcast domain define two important effects of the process of segmenting LANs using various devices. This section defines these terms to explain how hubs, switches, and routers impact collision domains and broadcast domains.

Collision Domains

Originally, the term *collision domain* referred to an Ethernet concept of all ports whose transmitted frames would cause a collision with frames sent by other devices in the collision domain. To review the core concept, Figure 6-8 illustrates collision domains.

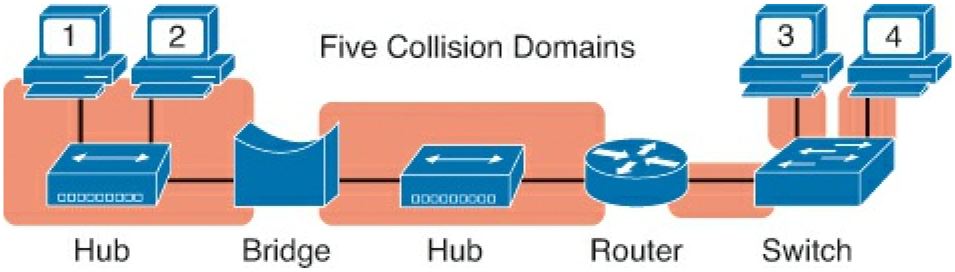


Figure 6-8. Collision Domains

> **Note**
>
> The LAN design in Figure 6-8 is not a typical design today. Instead, it simply provides enough information to help you compare hubs, switches, and routers.

First, pay attention to the devices in the figure. Of the four types of networking devices in the figure, only the hub allows a CD to spread from one side of the device to the other. The rest of the networking devices (routers, switches, bridges) all separate the LAN into separate ports.

Today, modern networks might not allow a collision to physically occur, but we still describe links as being in separate CDs. For example, consider the link from the switch to PC3. Physically, no collision could possibly occur. However, if PC3 and the LAN switch both enabled half-duplex, which uses CSMA/CD, they would consider their frames to collide if they were sent and received at the same time. So even today, we still talk about collision domains.

Broadcast Domains

Take any Ethernet LAN, and pick any device. Then think of that device sending an Ethernet broadcast. An Ethernet *broadcast domain* is the set of devices to which that broadcast is delivered.

Of all the network devices shown in Figure 6-8, only routers separate the LAN into multiple broadcast domains. LAN switches flood Ethernet broadcast frames, extending the scope of the broadcast domain. Routers do not forward Ethernet broadcast frames, either ignoring the frames, or processing and then discarding some broadcast from some overhead protocols used by routers. (Of the older Ethernet devices, bridges act like switches with broadcasts, and hubs repeat the signal, again not stopping the broadcasts.)

For perspective, Figure 6-9 provides the broadcast domains for the same network depicted in Figure 6-8.

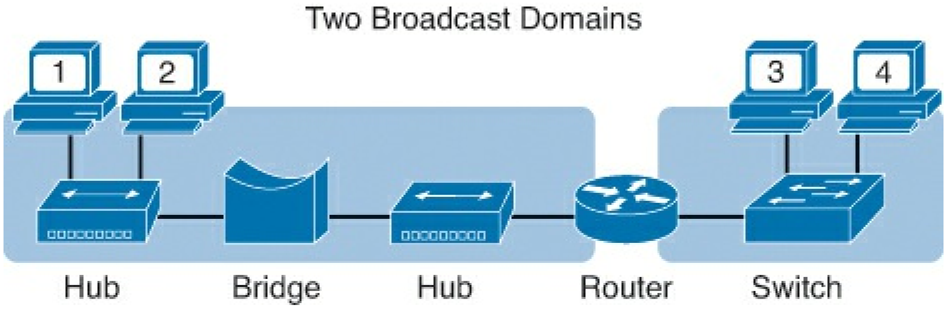


Figure 6-9. Broadcast Domains

By definition, broadcasts sent by a device in one broadcast domain are not forwarded to devices in another broadcast domain. In this example, there are two broadcast domains. For example, the router does not forward a LAN broadcast sent by a PC on the left to the network segment on the right.

General definitions for a collision domain and a broadcast domain are as follows:

Key Topic

- A *collision domain* is a set of network interface cards (NIC) for which a frame sent by one NIC could result in a collision with a frame sent by any other NIC in the same collision domain.
- A *broadcast domain* is a set of NICs for which a broadcast frame sent by one NIC is received by all other NICs in the same broadcast domain.

The Impact of Collision and Broadcast Domains on LAN Design

When designing a LAN, you need to keep in mind the trade-offs when choosing the number of devices in each collision domain and broadcast domain. First, consider the devices in a single collision domain for a moment. For a single collision domain:

- The devices share the available bandwidth.
- The devices might inefficiently use that bandwidth because of the effects of collisions, particularly under higher utilization.

For perspective on the impact of collision domains, it helps to compare an old design using LAN hubs to a newer design that uses the same speeds for each link, but instead uses a LAN switch. Consider a design with ten PCs, with each link using 100BASE-T. With a hub, only one PC can send at a time, for a theoretical maximum capacity of 100 Mbps for the entire LAN. Replace the hub with a switch, and you get

- 100 Mbps per link, for a total of 1000 Mbps (1 Gbps)
- The ability to use full-duplex on each link, effectively doubling the capacity to 2000 Mbps (2 Gbps)

The example of using hubs versus switches is admittedly a little old, but it shows one reason why no one chooses to use hubs, and why vendors now sell switches instead of hubs.

Now consider the issue of broadcasts. When a host receives a broadcast, the host must process the received frame. This means that the NIC must interrupt the computer's CPU, and the CPU must spend time thinking about the received broadcast frame. All hosts need to send some broadcasts to function properly. (For example, IP ARP messages are LAN broadcasts, as mentioned in Chapter 4, "Fundamentals of IPv4 Addressing and Routing.") So, broadcasts happen, which is good, but broadcasts do require all the hosts to spend time processing each broadcast frame.

Next, consider a large LAN, with multiple switches, with 500 PCs total. The switches create a single broadcast domain, so a broadcast sent by any of the 500 hosts should be sent to, and then processed by, all 499 other hosts. Depending on the number of broadcasts, the broadcasts could start to impact performance of the end-user PCs. However, a design that separated the 500 PCs into five groups of 100, separated from each other by a router, would create five broadcast domains. Now, a broadcast by one host would interrupt only 99 other hosts, and not the other 400 hosts, resulting in generally better performance on the PCs.

> **Note**
>
> Using smaller broadcast domains can also improve security, because of limiting broadcasts and because of robust security features in routers.

The choice about when to use a hub versus a switch was straightforward, but the choice of when to use a router to break up a large broadcast domain is more difficult. A meaningful discussion of the trade-offs and options is beyond the scope of this book. However, you should understand the concepts behind broadcast domains—specifically, that a router breaks LANs into multiple broadcast domains, but switches and hubs do not.

More importantly for the CCNA exams, you should be ready to react to questions in terms of the benefits of LAN segmentation instead of just asking for the facts related to collision domains and broadcast domains. Table 6-3 lists some of the key benefits. The features in the table should be interpreted within the following context: "Which of the following benefits are gained by using a hub/switch/router between Ethernet devices?"

Key Topic

Table 6-3. Benefits of Segmenting Ethernet Devices Using Hubs, Switches, and Routers

Feature	Hub	Switch	Router
Greater cabling distances are allowed	Yes	Yes	Yes
Creates multiple collision domains	No	Yes	Yes
Increases bandwidth	No	Yes	Yes
Creates multiple broadcast domains	No	No	Yes

Virtual LANs (VLAN)

Most every enterprise network today uses the concept of virtual LANs (VLAN). Before understanding VLANs, you must have a very specific understanding of the definition of a LAN. Although you can think about and define the term “LAN” from many perspectives, one perspective in particular will help you understand VLANs:

> A LAN consists of all devices in the same broadcast domain.

Without VLANs, a switch considers all interfaces on the switch, and the devices connected to those links, to be in the same broadcast domain. In other words, all connected devices are in the same LAN. (Cisco switches accomplish this by putting all interfaces in VLAN 1 by default.)

With VLANs, a switch groups interfaces into different VLANs (broadcast domains) based on configuration, with each interface in a different VLAN. Essentially, the switch creates multiple broadcast domains by putting some interfaces into one VLAN and other interfaces into other VLANs. So, instead of all ports on a switch forming a single broadcast domain, the switch separates them into many, based on configuration. It’s really that simple.

The next two figures compare two LANs for the purpose of explaining a little more about VLANs. First, before VLANs existed, if a design specified two separate broadcast domains, two switches would be used—one for each broadcast domain, as shown in Figure 6-10.

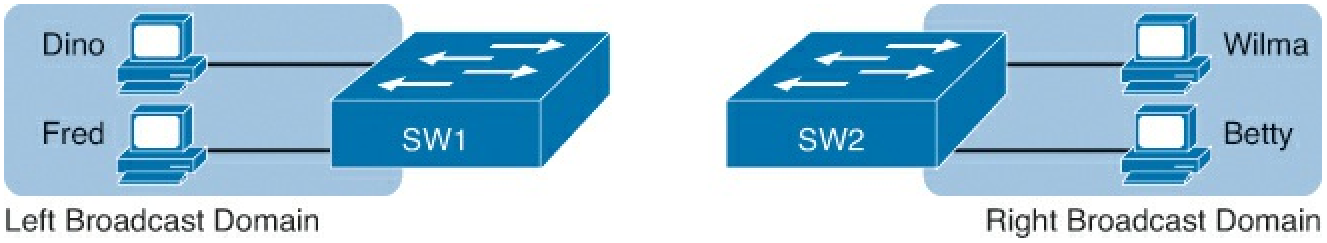


Figure 6-10. Sample Network with Two Broadcast Domains and No VLANs

Alternately, you can create multiple broadcast domains using a single switch. Figure 6-11 shows the same two broadcast domains as in Figure 6-10, now implemented as two different VLANs on a single switch.

Key Topic

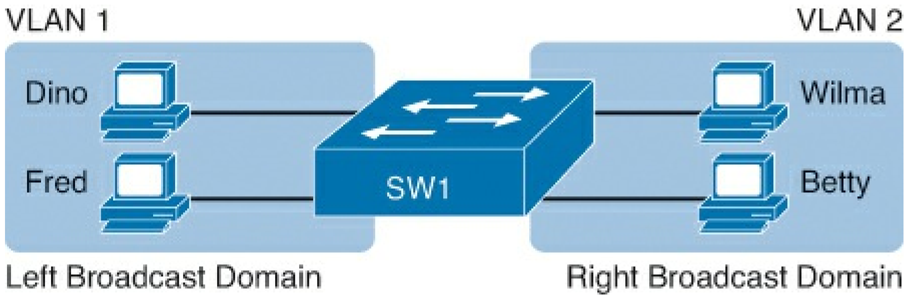


Figure 6-11. Sample Network with Two VLANs Using One Switch

This section briefly introduces the concept of VLANs, but Chapter 9, “Implementing Ethernet Virtual LANs,” discusses VLANs in more depth, including the details of how to configure VLANs in campus LANs.

Choosing Ethernet Technology for a Campus LAN

The term *campus LAN* refers to the LAN created to support larger buildings, or multiple buildings in somewhat close proximity to one another. For example, a company might lease office space in several buildings in the same office park. The network engineers can then build a campus LAN that includes switches in each building, plus Ethernet links between the switches in the buildings, to create a larger campus LAN.

When planning and designing a campus LAN, the engineers must consider the types of Ethernet available and the cabling lengths supported by each type. The engineers also need to choose the speeds required for each Ethernet segment. Additionally, some thought needs to be given to the idea that some switches should be used to connect directly to end-user devices, whereas other switches might need to simply connect to a large number of these end-user switches. Finally, most projects require that the engineer consider the type of equipment that is already installed and whether an increase in speed on some segments is worth the cost of buying new equipment.

This section discusses campus LAN design. It begins with some terminology Cisco uses for campus LAN design. Then, the text looks at the choice of what Ethernet standards to use for each link in the campus LAN, and why you might choose one versus another. This section ends with a popular tool to allow easy migration from older to newer (faster) Ethernet links using an Ethernet feature called autonegotiation.

Campus Design Terminology

To sift through all the requirements for a campus LAN, and then have a reasonable conversation about it with peers, most Cisco-oriented LAN designs use some common terminology to refer to the design. For this book's purposes, you should be aware of some of the key campus LAN design terminology.

Figure 6-12 shows a typical design of a large campus LAN, with the terminology included in the figure. This LAN has around 1000 PCs connected to switches that support around 25 ports each. Explanations of the terminology follow the figure.

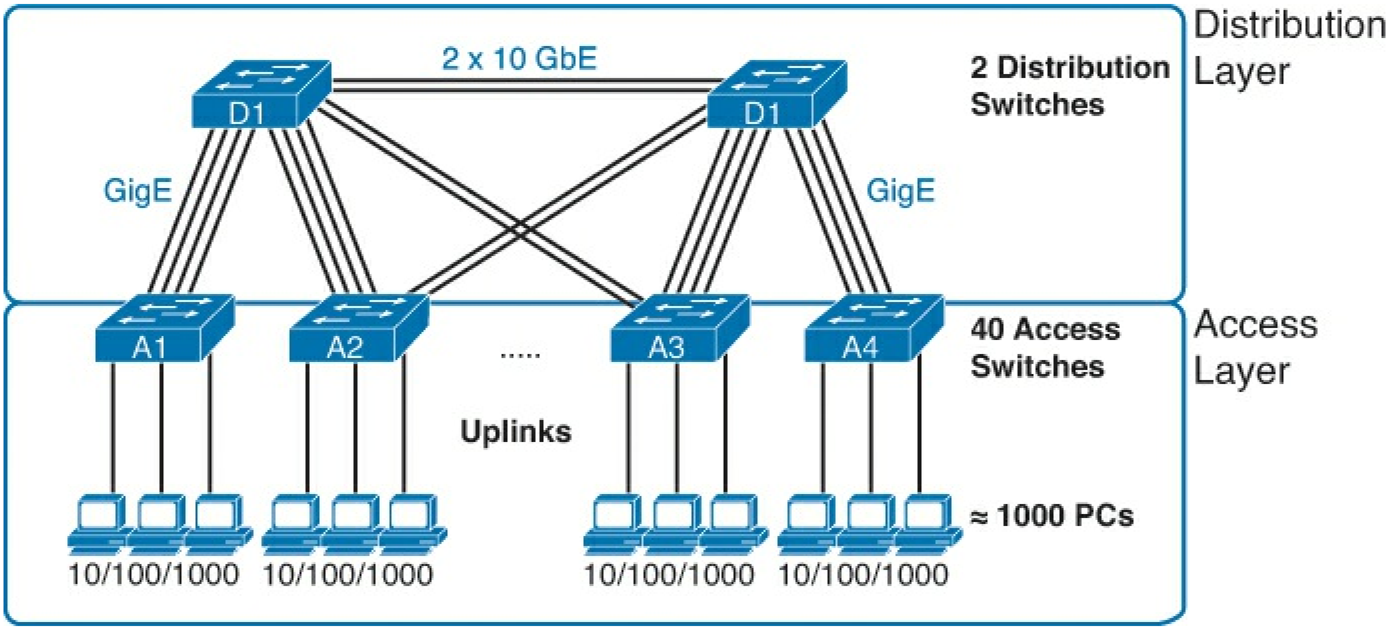


Figure 6-12. Campus LAN with Design Terminology Listed

Cisco uses three terms to describe the role of each switch in a campus design: *access*, *distribution*, and *core*. The roles differ based on whether the switch forwards traffic from user devices and the rest of the LAN (access), or whether the switch forwards traffic between other LAN switches (distribution and core).

Access switches connect directly to end users, providing user device access to the LAN. Access switches normally send traffic to and from the end-user devices to which they are connected and sit at the edge of the LAN.

In larger campus LANs, *distribution switches* provide a path through which the access switches can forward traffic to each other. By design, each of the access switches connects to at least one distribution switch, relying on distribution switches to forward traffic to other parts of the LAN. Note that most designs use at least two uplinks to two different distribution switches (as shown in Figure 6-12) for redundancy.

Using designs that connect a larger number of access switches to a small number of distribution switches reduces cabling needs while still allowing all devices to send data to all other devices in the LAN. For example, in Figure 6-12, the design could use a pair of links from each access switch to each of the two distribution switches, providing a great deal of redundancy. With four links for each of 40 access switches, the design uses 160 uplinks. If the design instead did not use distribution switches, to connect a single link between each pair of access switches would require 780 links.

The largest campus LANs often use *core switches* to forward traffic between distribution switches. For example, imagine a campus in which you had a LAN like Figure 6-12 in 12 buildings in the same office park. You could add two additional core switches, that serve a similar role as the distribution switches, connecting every distribution switch to the core. However, medium to smaller campus LANs often forego the concept of core switches.

The following list summarizes the terms that describe the roles of campus switches:

- **Access:** Provides a connection point (access) for end-user devices. Does not forward frames between two other access switches under normal circumstances.
- **Distribution:** Provides an aggregation point for access switches, forwarding frames between switches, but not connecting directly to end-user devices.
- **Core:** Aggregates distribution switches in very large campus LANs, providing very high forwarding rates.

Ethernet LAN Media and Cable Lengths

When designing a campus LAN, an engineer must consider the length of each cable run and then find the best type of Ethernet and cabling type that supports that length of cable. For example, if a company leases space in five buildings in the same office park, the engineer needs to figure out how long the cables between the buildings need to be and then pick the right type of Ethernet.

The three most common types of Ethernet today (10BASE-T, 100BASE-T, and 1000BASE-T) have the same 100-meter cable restriction, but they use slightly different cables. The EIA/TIA defines Ethernet cabling standards, including the cable's quality. Each Ethernet standard that uses UTP cabling lists a cabling quality category as the minimum category that the standard supports. For example, 10BASE-T allows for Category 3 (CAT3) cabling or better, whereas 100BASE-T calls for higher-quality CAT5 cabling, and 1000BASE-T requires even higher-quality CAT5e or CAT6 cabling. If an engineer plans on using existing cabling, he or she must be aware of the types of UTP cables and the speed restrictions implied by the type of Ethernet the cabling supports.

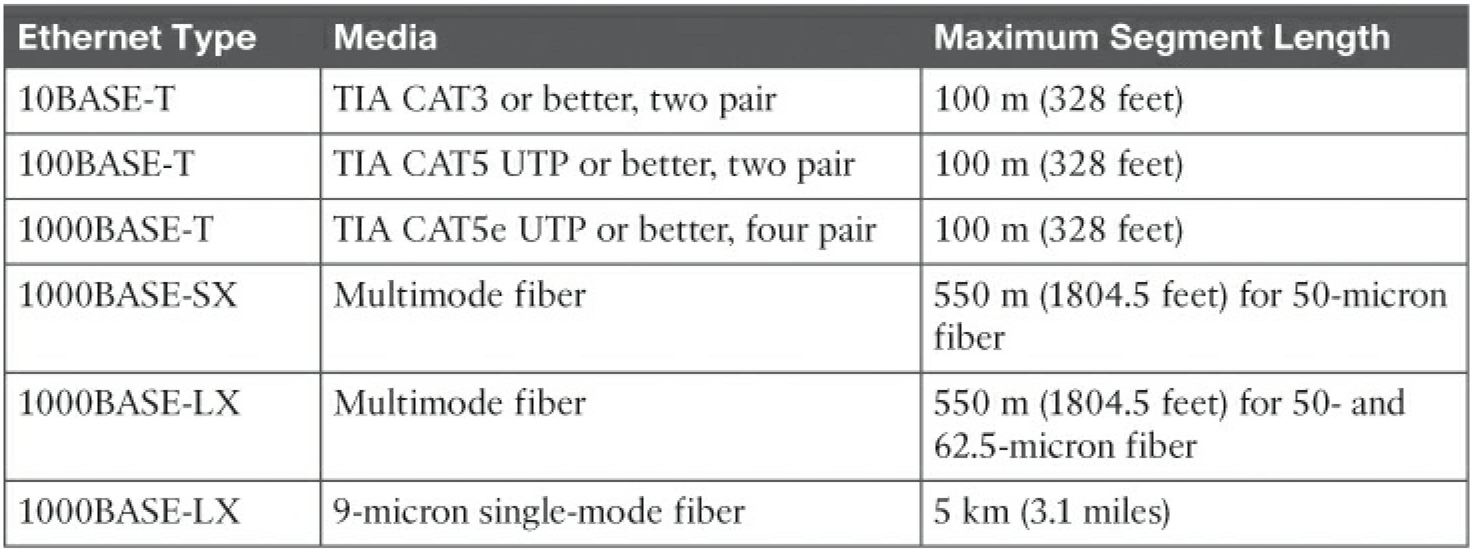
Several types of Ethernet define the use of fiber-optic cables. UTP cables include copper wires over which electrical currents can flow, whereas optical cables include ultrathin strands of glass through which light can pass. To send bits, the switches can alternate between sending brighter and dimmer light to encode 0s and 1s on the cable.

Optical cables support a variety of much longer distances than the 100 meters supported by Ethernet on UTP cables. Optical cables experience much less interference from outside sources as compared to copper cables. Additionally, switches can use lasers to generate the light, as well as light-emitting diodes (LED). Lasers allow for even longer cabling distances, in the thousands of meters, at higher cost, whereas less-expensive LEDs might well support plenty of distance for campus LANs in most office parks.

Finally, the type of optical cabling can also impact the maximum distances per cable. Of the two types, multimode fiber supports shorter distances, but it is generally cheaper cabling and it works fine with less-expensive LEDs. The other optical cabling type, single-mode fiber, supports the longest distances but is more expensive. Also note that LED-based hardware, often used with multimode fiber, is much less expensive than laser-based hardware, often used with single-mode fiber.

Table 6-4 lists the more common types of Ethernet and their cable types and length limitations.

Table 6-4. Ethernet Types, Media, and Segment Lengths (Per IEEE)



Ethernet Type	Media	Maximum Segment Length
10BASE-T	TIA CAT3 or better, two pair	100 m (328 feet)
100BASE-T	TIA CAT5 UTP or better, two pair	100 m (328 feet)
1000BASE-T	TIA CAT5e UTP or better, four pair	100 m (328 feet)
1000BASE-SX	Multimode fiber	550 m (1804.5 feet) for 50-micron fiber
1000BASE-LX	Multimode fiber	550 m (1804.5 feet) for 50- and 62.5-micron fiber
1000BASE-LX	9-micron single-mode fiber	5 km (3.1 miles)

Most engineers simply remember the general distance limitations and then use a reference chart (such as Table 6-4) to remember each specific detail. An engineer must also consider the physical paths that the cables will use to run through a campus or building and the impact on the required cable length. For example, a cable might have to run from one end of the building to the other, then through a conduit that connects the floors of the building, and then horizontally to a wiring closet on another floor. Often those paths are not the shortest way to get from one place to the other. So, the chart's details are important to the LAN planning process and the resulting choice of LAN media.

Autonegotiation

Ethernet devices on the ends of a link must use the same standard or they cannot correctly send data. For example, a NIC cannot use 100BASE-T, which uses a two-pair UTP cable with a 100-Mbps speed, while the switch port on the other end of the link uses 1000BASE-T. Even if you used a cable that works with Gigabit Ethernet, the link would not work with one end trying to send at 100 Mbps while the other tried to receive the data at 1000 Mbps.

Upgrading to new and faster Ethernet standards becomes a problem because both ends have to use the same standard. For example, if you replace an old PC with a new one, the old one might have been using 100BASE-T while the new one uses 1000BASE-T. The switch port on the other end of the link needs to now use 1000BASE-T, so you upgrade the switch. If that switch had ports that would only use 1000BASE-T, you would need to upgrade all the other PCs connected to the switch.

The IEEE gives us a nice solution to this migration problem: IEEE autonegotiation. IEEE autonegotiation (IEEE standard 802.3u) defines a protocol that lets the two UTP-based Ethernet nodes on a link negotiate so that they each choose to use the same speed and duplex settings. The protocol messages flow outside the normal Ethernet electrical frequencies as out-of-band signals over the UTP cable. Basically, each node states what it can do, and then each node picks the best options that both nodes support: the fastest speed and the best duplex setting, with full-duplex being better than half-duplex.

> **Note**
>
> Autonegotiation relies on the fact that the IEEE uses the same wiring pinouts for 10BASE-T and 100BASE-T, and that 1000BASE-T simply adds to those pinouts, adding two pair.

Many networks use autonegotiation every day, particularly between user devices and the access layer LAN switches, as shown in Figure 6-13. The company installed four-pair cabling to be ready to support Gigabit Ethernet, so the wiring works for the 10-Mbps, 100-Mbps, and 1000-Mbps Ethernet options. Both nodes on each link send autonegotiation messages to each other. The switch in this case has all 10/100/1000 ports, while the PC NICs support different options.

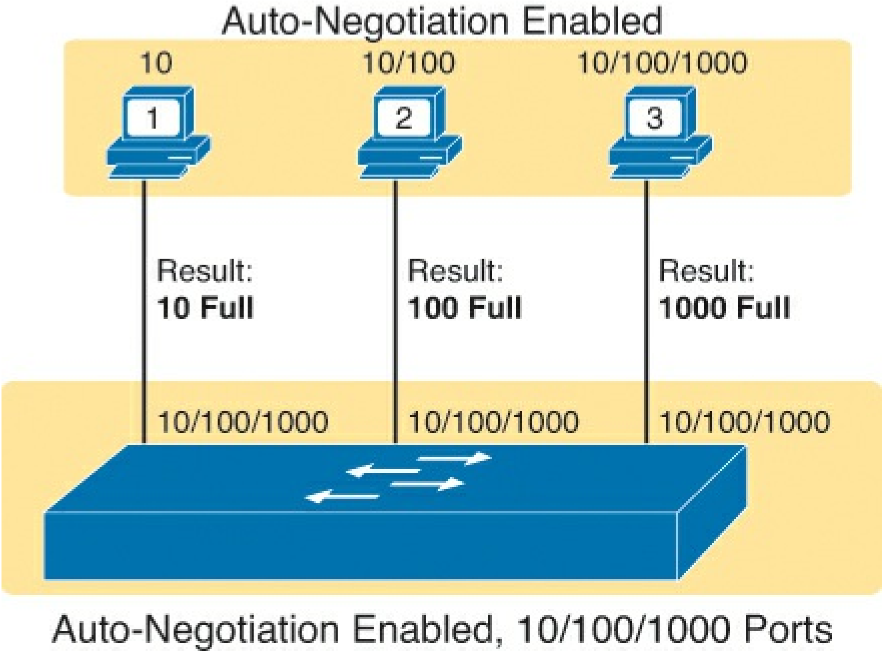


Figure 6-13. IEEE Autonegotiation Results with Both Nodes Working Correctly

The following list breaks down the logic, one PC at a time:

PC1: The switch port claims it can go as fast as 1000 Mbps, but PC1's NIC claims a top speed of 10 Mbps. Both the PC and switch choose the best speed both support (10 Mbps) and the best duplex (full).

PC2: PC2 claims a best speed of 100 Mbps, which means it can use 10BASE-T or 100BASE-T. The switch port and NIC negotiate to use the best speed of 100 Mbps and full-duplex.

PC3: It uses a 10/100/1000 NIC, supporting all three speeds and standards, so both the NIC and switch port choose 1000 Mbps and full-duplex.

Autonegotiation Results When Only One Node Uses Autonegotiation

Figure 6-13 shows the IEEE autonegotiation results when both nodes use the process. However, most Ethernet devices can disable autonegotiation, so it is just as important to know what happens when a node tries to use autonegotiation but the node gets no response.

Disabling autonegotiation is not always a bad idea, but generally you should either use it on both ends of the link or disable it on both ends of the link. For example, many network engineers disable autonegotiation on links between switches and simply configure the desired speed and duplex on both switches. If enabled on both ends of the link, the nodes should pick the best speed and duplex. However, when enabled on only one end, many issues can arise: The link might not work at all, or it might just work poorly.

IEEE autonegotiation defines some rules (defaults) that nodes should use when autonegotiation fails, as follows:

- **Speed:** Use your slowest supported speed (often 10 Mbps).
- **Duplex:** If your speed = 10 or 100, use half-duplex; otherwise, use full-duplex.

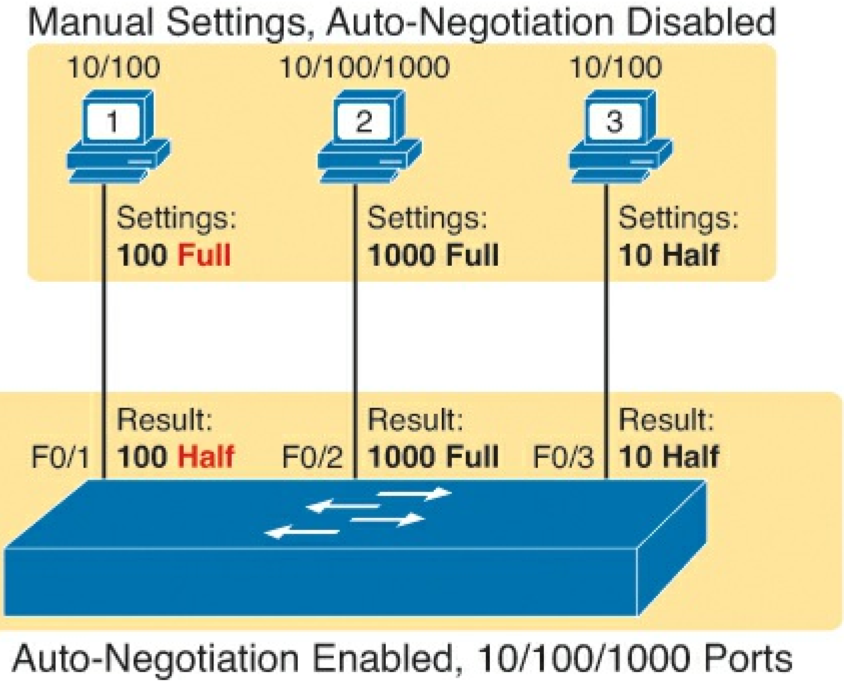
Cisco switches also add to the base IEEE logic, because Cisco switches can actually sense the speed used by other node, even without IEEE autonegotiation. As a result, Cisco switches use this slightly different logic when autonegotiation fails:

Key Topic

- **Speed:** Sense the speed (without using autonegotiation), or if that fails, use the IEEE default (slowest supported speed, often 10 Mbps).

- **Duplex:** Use the IEEE defaults: If speed = 10 or 100, use half-duplex; otherwise, use full-duplex.

Figure 6-14 shows three examples in which three users change their NIC settings and disable autonegotiation. The switch has all 10/100/1000 ports, with autonegotiation enabled. The top of the figure shows the configured settings on each PC NIC, with the choices made by the switch listed next to each switch port.



Manual Settings, Auto-Negotiation Disabled
10/100
10/100/1000
10/100
1
2
3
Settings:
100 Full
Settings:
1000 Full
Settings:
10 Half
Result:
F0/1
100 Half
Result:
F0/2
1000 Full
Result:
F0/3
10 Half
Auto-Negotiation Enabled, 10/100/1000 Ports

Figure 6-14. IEEE Autonegotiation Results with Autonegotiation Disabled on One Side

Reviewing each link, left to right:

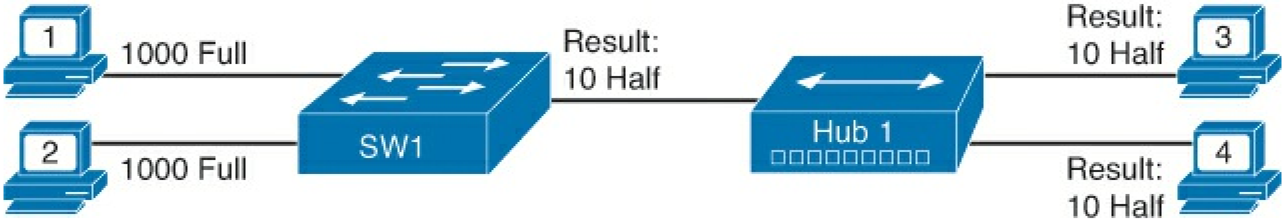
- **PC1:** The switch receives no autonegotiation messages, so it senses the electrical signal to learn that PC1 is sending data at 100 Mbps. The switch uses the IEEE default duplex based on the 100 Mbps speed (half-duplex).
- **PC2:** The switch uses the same steps and logic as with the link to PC1, except that the switch chooses to use full-duplex, because the speed is 1000 Mbps.
- **PC3:** The user picks poorly, choosing the slower speed (10 Mbps) and the worse duplex setting (half). However, the Cisco switch senses the speed without using IEEE autonegotiation and then uses the IEEE duplex default for 10-Mbps links (half-duplex).

PC1 shows a classic and unfortunately common end result: a *duplex mismatch*. The two nodes (PC1 and SW1's port F0/1) both use 100 Mbps, so they can send data. However, PC1, using full-duplex, does not attempt to use CSMA/CD logic and sends frames at any time. Switch port F0/1, with half-duplex, does use CSMA/CD. As a result, switch port F0/1 will believe collisions occur on the link, even if none physically occur. The switch port will stop transmitting, back off, resend frames, and so on. As a result, the link is up, but it performs poorly.

Autonegotiation and LAN Hubs

LAN hubs also impact how autonegotiation works. Basically, hubs do not react to autonegotiation messages, and they do not forward the messages. As a result, devices connected to a hub must use the IEEE rules for choosing default settings, which often results in the devices using 10 Mbps and half-duplex.

Figure 6-15 shows an example of a small Ethernet LAN that uses a 20-year-old 10BASE-T hub. In this LAN, all devices and switch ports are 10/100/1000 ports. The hub supports only 10BASE-T.



1
1000 Full
2
1000 Full
SW1
Result:
10 Half
Hub 1
Result:
10 Half
3
Result:
10 Half
4

Figure 6-15. IEEE Autonegotiation with a LAN Hub

Note that the devices on the right need to use half-duplex, because the hub requires the use of the CSMA/CD algorithm to avoid collisions.

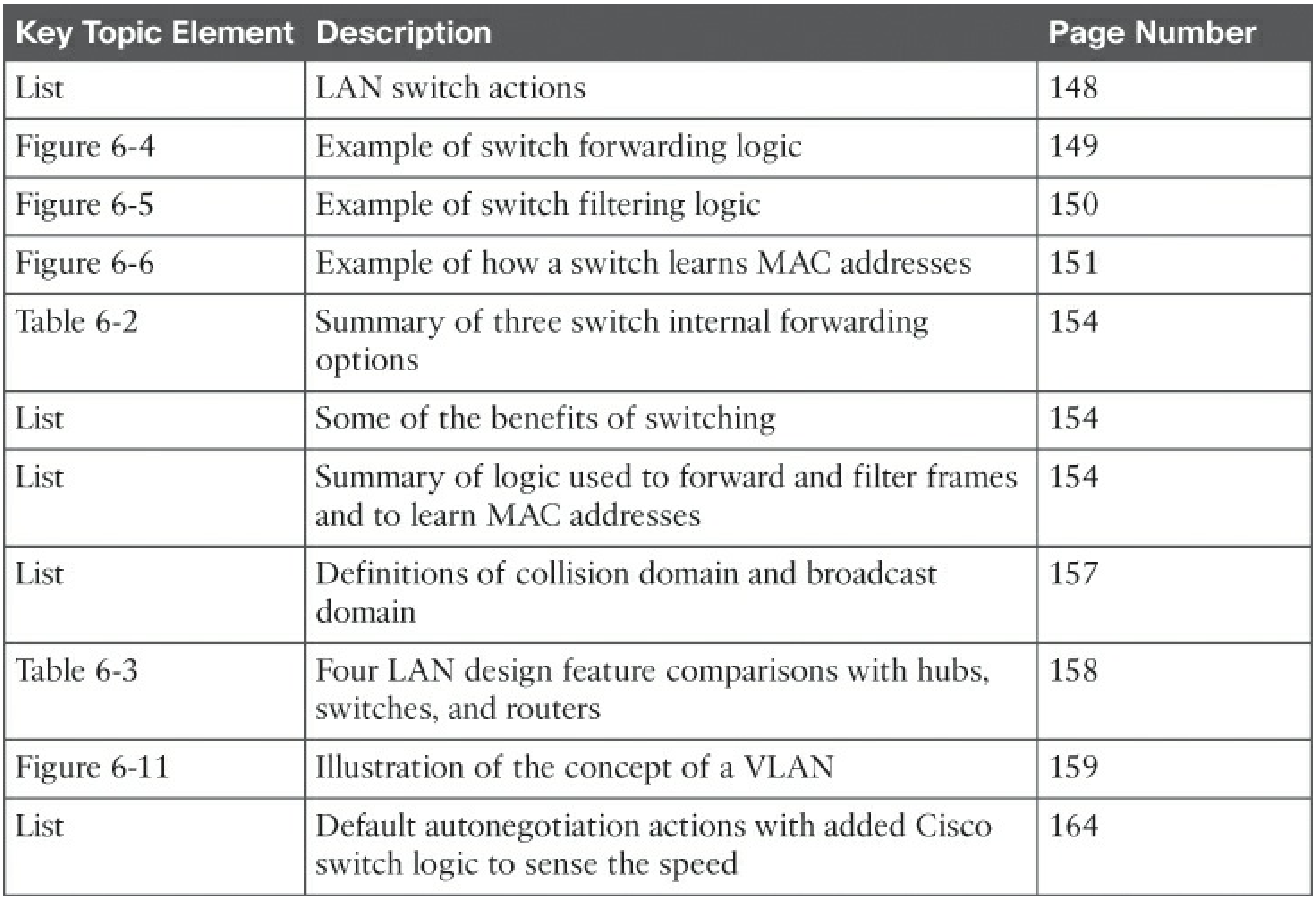
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 6-5 lists these key topics and where each is discussed.

Key Topic

Table 6-5. Key Topics for Chapter 6



Key Topic Element	Description	Page Number
List	LAN switch actions	148
Figure 6-4	Example of switch forwarding logic	149
Figure 6-5	Example of switch filtering logic	150
Figure 6-6	Example of how a switch learns MAC addresses	151
Table 6-2	Summary of three switch internal forwarding options	154
List	Some of the benefits of switching	154
List	Summary of logic used to forward and filter frames and to learn MAC addresses	154
List	Definitions of collision domain and broadcast domain	157
Table 6-3	Four LAN design feature comparisons with hubs, switches, and routers	158
Figure 6-11	Illustration of the concept of a VLAN	159
List	Default autonegotiation actions with added Cisco switch logic to sense the speed	164

Complete the Tables and Lists from Memory

Print a copy of Appendix M, "Memory Tables" (found on the DVD), or at least the section for this chapter, and complete the tables and lists from memory. Appendix N, "Memory Tables Answer Key," also on the DVD, includes completed tables and lists for you to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

- autonegotiation
- broadcast domain

- broadcast frame
- collision domain
- cut-through switching
- flooding
- fragment-free switching
- Spanning Tree Protocol (STP)
- store-and-forward switching
- unknown unicast frame
- virtual LAN

Chapter 7. Installing and Operating Cisco LAN Switches

This chapter covers the following exam topics:

LAN Switching Technologies

Configure and verify initial switch configuration including remote access management.

Cisco IOS commands to perform basic switch setup

Verify network status and switch operation using basic utilities such as ping, telnet and ssh.

When you buy a Cisco Catalyst switch, you can take it out of the box, power on the switch by connecting the power cable to the switch and a power outlet, and connect hosts to the switch using the correct UTP cables, and the switch works. You do not have to do anything else, and you certainly do not have to tell the switch to start forwarding Ethernet frames. The switch uses default settings so that all interfaces will work, assuming that the right cables and devices connect to the switch, and the switch forwards frames in and out of each interface.

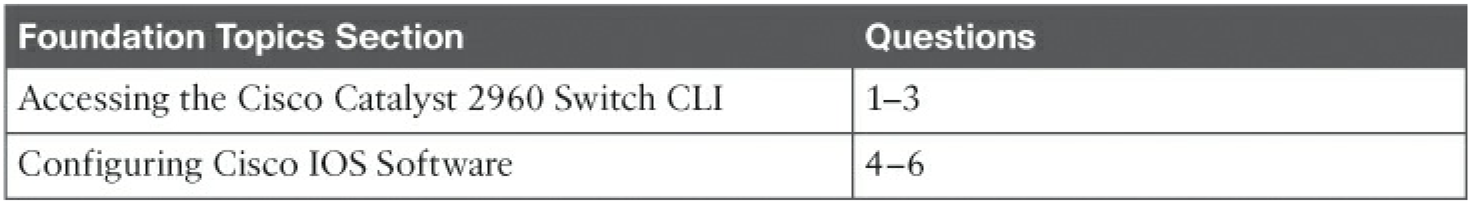
However, most enterprises will want to be able to check on the switch's status, look at information about what the switch is doing, and possibly configure specific features of the switch. Engineers will also want to enable security features that allow them to securely access the switches without being vulnerable to malicious people breaking into the switches. To perform these tasks, a network engineer needs to connect to the switch's user interface.

This chapter explains the details of how to access a Cisco switch's user interface, how to use commands to find out how the switch is currently working, and how to configure the switch to tell it what to do. This chapter focuses on the processes, introducing several commands while introducing the process. The remaining chapters in Part II of the book focus on commands to do particular tasks.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C. "Answers to the 'Do I Know This Already?' Quizzes."

Table 7-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Accessing the Cisco Catalyst 2960 Switch CLI	1–3
Configuring Cisco IOS Software	4–6

1. In what modes can you execute the command **show mac address-table**? (Choose two answers.)
   - **a.** User mode
   - **b.** Enable mode
   - **c.** Global configuration mode
   - **d.** Interface configuration mode
2. In which of the following modes of the CLI could you issue the command **reload** to reboot the switch?
   - **a.** User mode
   - **b.** Enable mode
   - **c.** Global configuration mode
   - **d.** Interface configuration mode
3. Which of the following is a difference between Telnet and SSH as supported by a Cisco switch?
   - **a.** SSH encrypts the passwords used at login, but not other traffic; Telnet encrypts nothing.
   - **b.** SSH encrypts all data exchange, including login passwords; Telnet encrypts nothing.
   - **c.** Telnet is used from Microsoft operating systems, and SSH is used from UNIX and Linux operating systems.
   - **d.** Telnet encrypts only password exchanges; SSH encrypts all data exchanges.
4. What type of switch memory is used to store the configuration used by the switch when it is up and working?
   - **a.** RAM
   - **b.** ROM
   - **c.** Flash
   - **d.** NVRAM
   - **e.** Bubble
5. What command copies the configuration from RAM into NVRAM?
   - **a. copy running-config tftp**

- **b. copy tftp running-config**
- **c. copy running-config startup-config**
- **d. copy startup-config running-config**
- **e. copy startup-config running-config**
- **f. copy running-config startup-config**

6. A switch user is currently in console line configuration mode. Which of the following would place the user in enable mode? (Choose two answers.)
   - **a.** Using the **exit** command once
   - **b.** Using the **end** command once
   - **c.** Pressing the Ctrl-Z key sequence once
   - **d.** Using the **quit** command

Answers to the "Do I Know This Already?" quiz:

1 A and B **2** B **3** B **4** A **5** F **6** B and C

Foundation Topics

Accessing the Cisco Catalyst 2960 Switch CLI

Cisco uses the concept of a *command-line interface (CLI)* with its router products and most of its Catalyst LAN switch products. The CLI is a text-based interface in which the user, typically a network engineer, enters a text command and presses Enter. Pressing Enter sends the command to the switch, which tells the device to do something. The switch does what the command says, and in some cases, the switch replies with some messages stating the results of the command.

Cisco Catalyst switches also support other methods to both monitor and configure a switch. For example, a switch can provide a web interface, so that an engineer can open a web browser to connect to a web server running in the switch. Switches also can be controlled and operated using network management software, as discussed briefly in the ICND2 book.

This book discusses only Cisco Catalyst enterprise-class switches, and in particular, how to use the Cisco CLI to monitor and control these switches. This first major section of the chapter first examines these Catalyst switches in more detail, and then explains how a network engineer can get access to the CLI to issue commands.

Cisco Catalyst Switches and the 2960 Switch

Within the Cisco Catalyst brand of LAN switches, Cisco produces a wide variety of switch series or families. Each switch series includes several specific models of switches that have similar features, similar price-versus-performance trade-offs, and similar internal components.

Cisco positions the 2960 series (family) of switches as full-featured, low-cost wiring closet switches for enterprises. That means that you would expect to use 2960 switches as access switches, as shown in Figure 6-12 in Chapter 6, "Building Ethernet LANs with Switches."

Figure 7-1 shows a photo of the 2960 switch series from Cisco. Each switch is a different specific model of switch inside the 2960 series. For example, three of the five switches have 48 RJ-45 UTP 10/100 ports, meaning that these ports can autonegotiate the use of 10BASE-T or 100BASE-T Ethernet. These switches also have a few 10/100/1000 interfaces on the right, intended to connect to the core of an enterprise campus LAN.

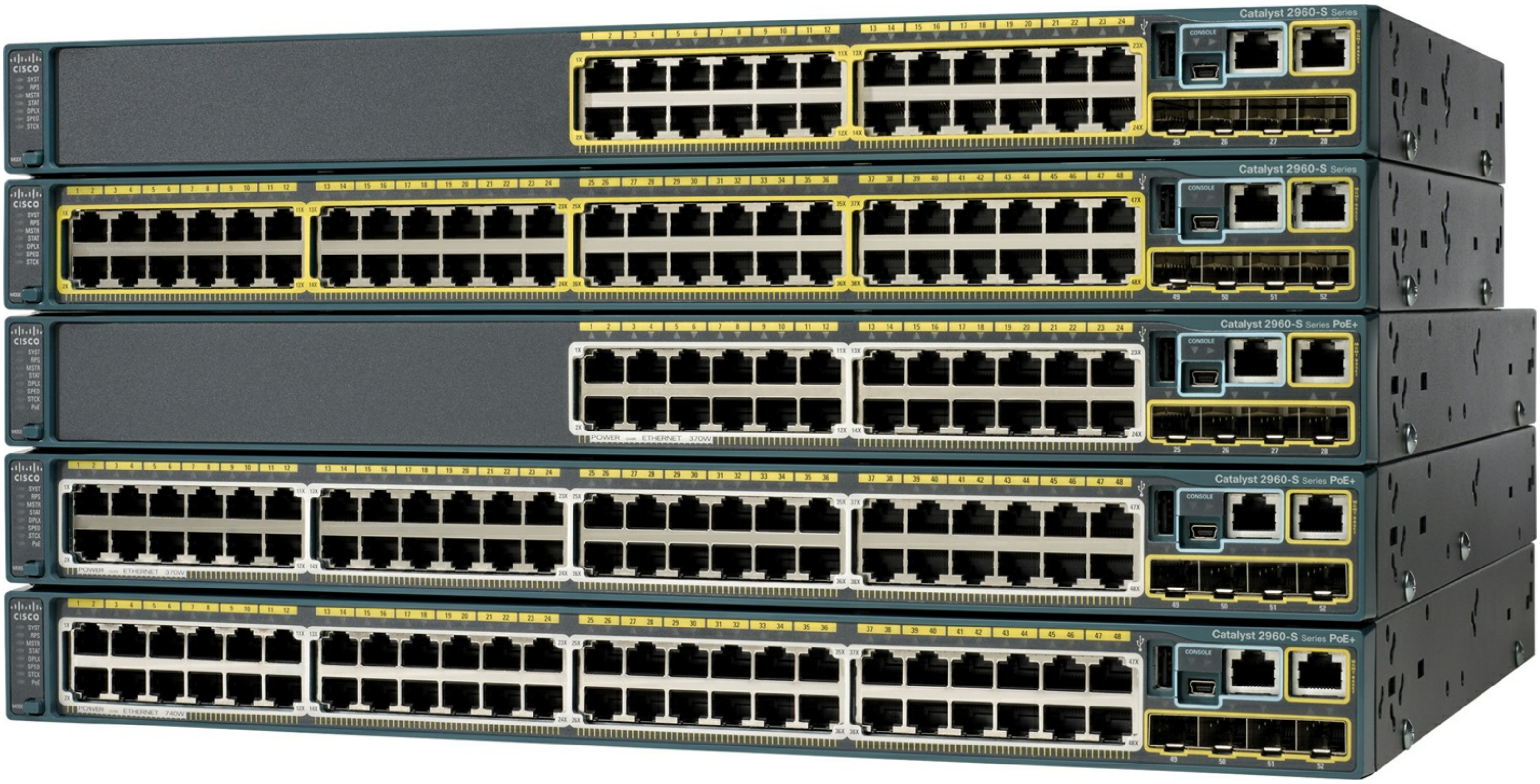


Figure 7-1. Cisco 2960 Catalyst Switch Series

Cisco refers to a switch's physical connectors as either *interfaces* or *ports*. Each interface has a number in the style *x*/*y*, where *x* and *y* are two different numbers. On a 2960, the numbering of 10/100 interfaces starts at 0/1, the second is 0/2, and so on. The interfaces also have names; for example, "interface FastEthernet 0/1" is the first of the 10/100 interfaces. Any Gigabit-capable interfaces would be called "GigabitEthernet" interfaces. For example, the first 10/100/1000 interface on a 2960 would be "interface GigabitEthernet 1/1."

Switch Status from LEDs

When an engineer needs to examine how a switch is working to verify its current status and to troubleshoot any problems, the vast majority of the time is spent using commands from the Cisco IOS CLI. However, the switch hardware does include several LEDs that provide some status and troubleshooting information, both during the time right after the switch has been powered on and during ongoing operations. Before moving on to discuss the CLI, this brief section examines the switch LEDs and their meanings.

Most Cisco Catalyst switches have some LEDs, including an LED for each physical Ethernet interface. For example, Figure 7-2 shows the front of a 2960 series switch, with five LEDs on the left, one LED over each port, and a mode button.

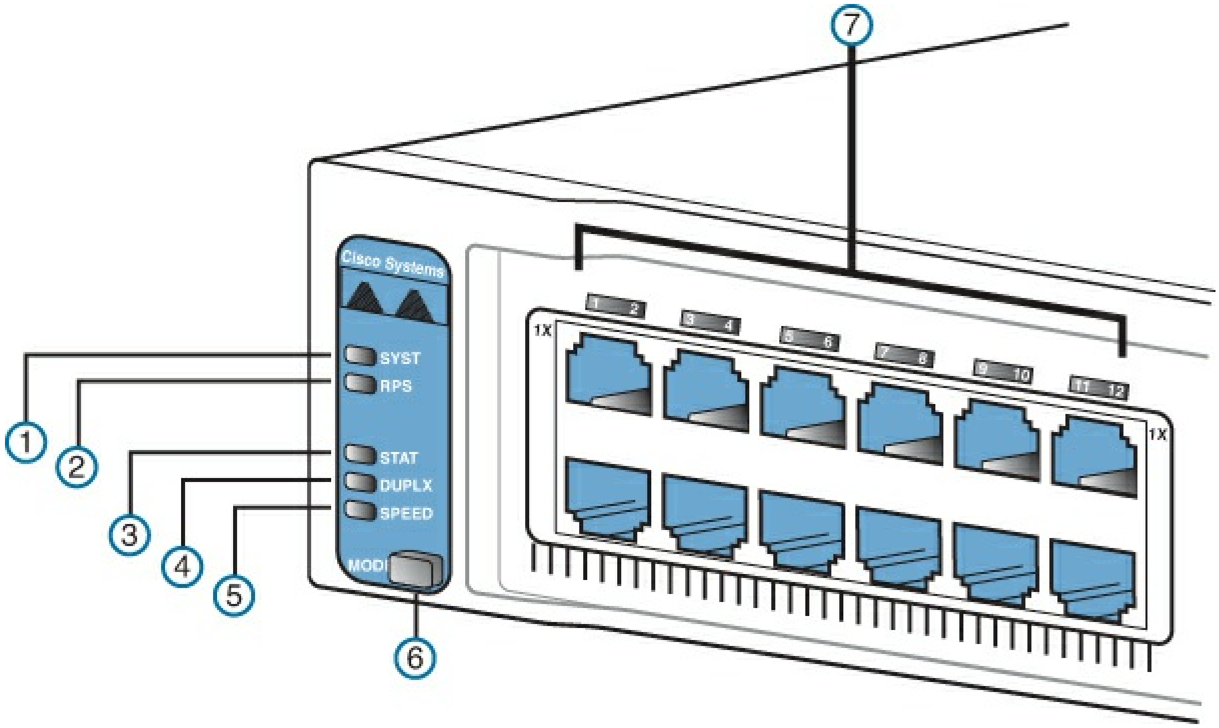
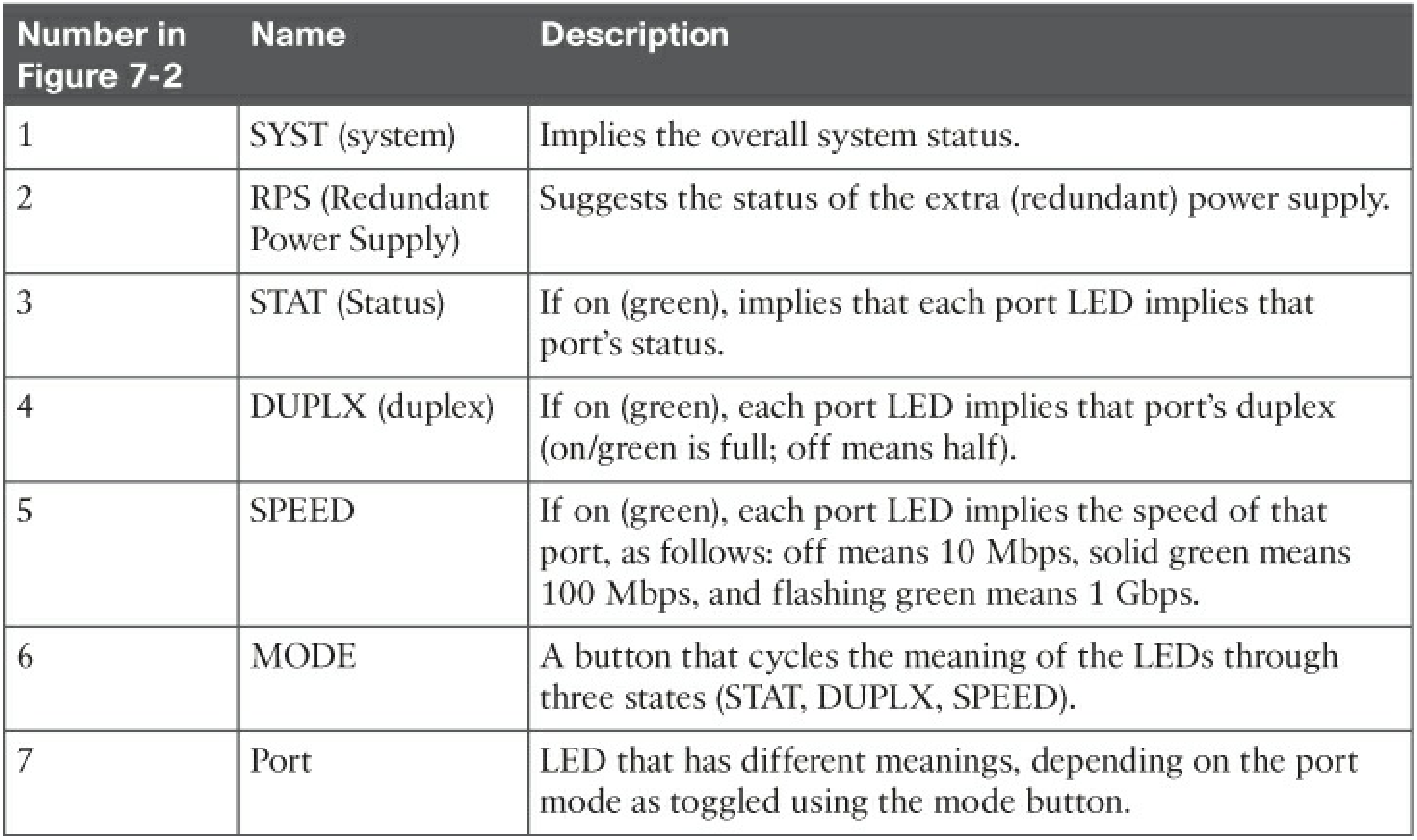


Figure 7-2. 2960 LEDs and a Mode Button

The figure points out the various LEDs, with various meanings. Table 7-2 summarizes the LEDs, and additional explanations follow the table.

Table 7-2. LEDs and One Button in Figure 7-2



Number in Figure 7-2	Name	Description
1	SYST (system)	Implies the overall system status.
2	RPS (Redundant Power Supply)	Suggests the status of the extra (redundant) power supply.
3	STAT (Status)	If on (green), implies that each port LED implies that port's status.
4	DUPLX (duplex)	If on (green), each port LED implies that port's duplex (on/green is full; off means half).
5	SPEED	If on (green), each port LED implies the speed of that port, as follows: off means 10 Mbps, solid green means 100 Mbps, and flashing green means 1 Gbps.
6	MODE	A button that cycles the meaning of the LEDs through three states (STAT, DUPLX, SPEED).
7	Port	LED that has different meanings, depending on the port mode as toggled using the mode button.

A few specific examples can help make sense of the LEDs. For example, consider the SYST LED for a moment. This LED provides a quick overall status of the switch, with three simple states on most 2960 switch models:

- **Off:** The switch is not powered on.
- **On (green):** The switch is powered on and operational (Cisco IOS has been loaded).
- **On (amber):** The system has power, but is not functioning properly.

So, a quick look at the SYST LED on the switch tells you whether the switch is working and, if it isn't, whether this is because of a loss of power (the SYST LED is off) or some kind of problem loading IOS (LED amber). In this last case, the typical response is to power the switch off and back on again. If the same failure occurs, a call to the Cisco Technical Assistance Center (TAC) is typically the next step.

Besides the straightforward SYST LED, the port LEDs—the LEDs sitting above or below each Ethernet port—mean something different depending on which of three port LED modes is currently used on the switch. The switches have a mode button (labeled with the number 6 in Figure 7-2) that, when pressed, cycles the port LEDs through three modes: STAT, DUPLX, and SPEED. The current port LED mode is signified by a solid green STAT, DUPLX, or SPEED LED (the lower three LEDs on the left part of Figure 7-2, labeled 3, 4, and 5). To move to another port LED mode, the engineer simply presses the mode button another time or two.

For example, in STAT (status) mode, each port LED implies the state of the matching port, as follows:

- **Off:** The link is currently not working (including if shut down).
- **Solid green:** The link is working, but there's no current traffic.
- **Flashing green:** The link is working, and traffic is currently passing over the interface.
- **Flashing amber:** The port is blocked by spanning tree.

In contrast, in SPEED port LED mode, the port LEDs imply the operating speed of the interface, with an unlit LED meaning 10 Mbps, a solid green light meaning 100 Mbps, and flashing green meaning 1000 Mbps (1 Gbps).

The particular details of how each LED works differ between different Cisco switch families and with different models inside the same switch family. So, memorizing the specific meaning of particular LED combinations is probably not required, and this chapter does not attempt to cover all combinations for even a single switch. However, it is important to remember the general ideas, the concept of a mode button that changes the meaning of the port LEDs, and the three meanings of the SYST LED mentioned earlier in this section.

The vast majority of the time, switches power up just fine and load Cisco IOS, and then the engineer simply accesses the CLI to operate and examine the switch. Next, the chapter focuses on the details of how to access the CLI.

Accessing the Cisco IOS CLI

Like any other piece of computer hardware, Cisco switches need some kind of operating system software. Cisco calls this OS the *Internetwork Operating System (IOS)*.

Cisco IOS Software for Catalyst switches implements and controls logic and functions performed by a Cisco switch. Besides controlling the switch's performance and behavior, Cisco IOS also defines an interface for humans called the CLI. The Cisco IOS CLI allows the user to use a terminal emulation program, which accepts text entered by the user. When the user presses Enter, the terminal emulator sends that text to the switch. The switch processes the text as if it is a command, does what the command says, and sends text back to the terminal emulator.

The switch CLI can be accessed through three popular methods—the console, Telnet, and Secure Shell (SSH). Two of these methods (Telnet and SSH) use the IP network in which the switch resides to reach the switch. The console is a physical port built specifically to allow access to the CLI. Figure 7-3 depicts the options.

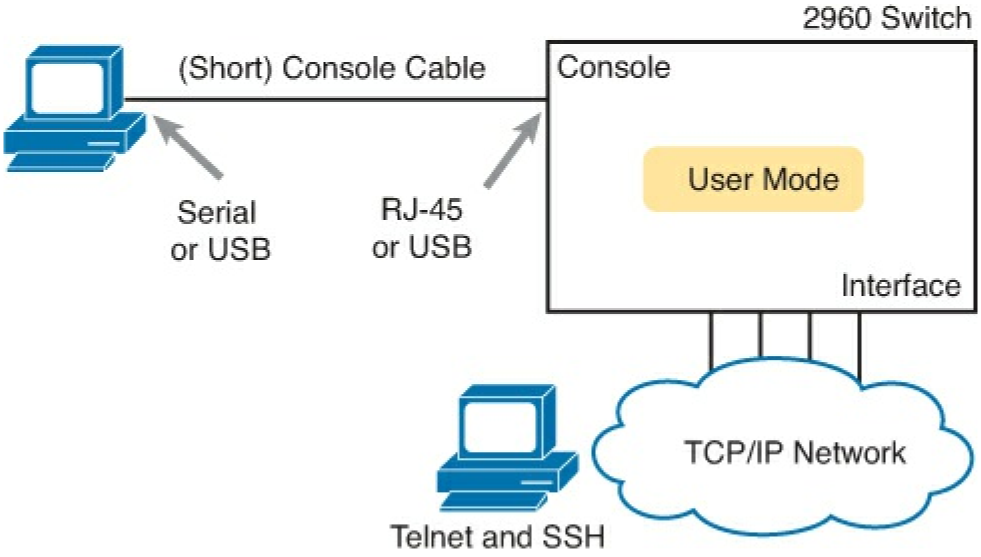


Figure 7-3. CLI Access

Console access requires both a physical connection between a PC (or other user device) and the switch's console port, as well as some software on the PC. Telnet and SSH require software on the user's device, but they rely on the existing TCP/IP network to transmit data. The next few pages detail how to connect the console and set up the software for each method to access the CLI.

Cabling the Console Connection

The physical console connection, both old and new, uses three main components: the physical console port on the switch, a physical serial port on the PC, and a cable that works with the console and serial ports. However, the physical cabling details have changed slowly over time, mainly because of advances and changes with PC hardware.

Older console connections use a PC serial port, a console cable, and an RJ-45 connector on the switch. The PC serial port typically has a D-shell connector (roughly rectangular) with nine pins (often called a DB-9). Older switches, as well as some current models, use an RJ-45 connector for the console port. Figure 7-4 shows the cabling on the left.

Key Topic

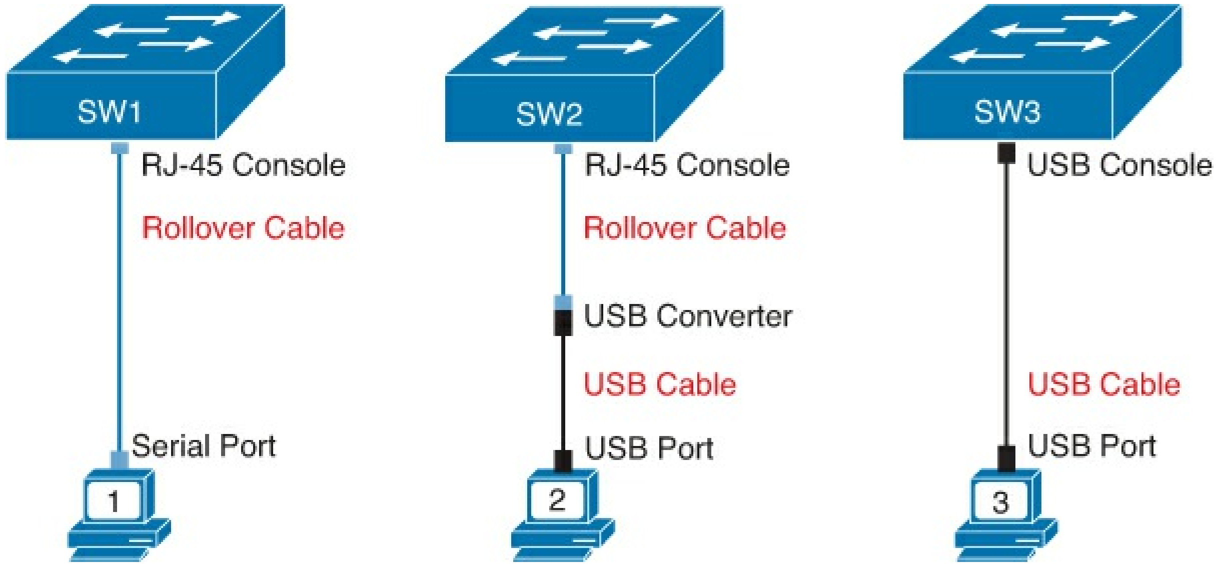


Figure 7-4. Console Connection to a Switch

You can use either a purpose-built console cable (which ships with new Cisco switches and routers) or make your own console cable using UTP cables and a standard RJ-45–to–DB-9 converter plug. You can buy the converter plug at most computer stores. Then, for the UTP cabling, the cable uses rollover cable pinouts, rather than any of the standard Ethernet cabling pinouts. Instead, it uses eight wires, rolling the wire at pin 1 to pin 8, pin 2 to pin 7, pin 3 to pin 6, and so on.

PCs have migrated away from using serial ports to instead use Universal Serial Bus (USB) ports for serial communications. Cisco has also begun building newer routers and switches with USB ports for console access as well. In the simplest form, you can use any USB port on the PC, with a USB cable, connected to the USB console port on the switch or router, as shown on the far right side of Figure 7-4.

The middle part of the figure shows yet another common option. Many PCs no longer have serial ports, but many existing Cisco routers and switches have only an RJ-45 console port and no USB console port. To connect such a PC to a router or switch console, you need some kind of converter that converts from the older console cable to a USB connector, as shown in the middle of Figure 7-4.

Note

When using the USB options, you typically also need to install a software driver so that your PC's OS knows that the device on the other end of the USB connection is the console of a Cisco device.

Configuring the Terminal Emulator for the Console

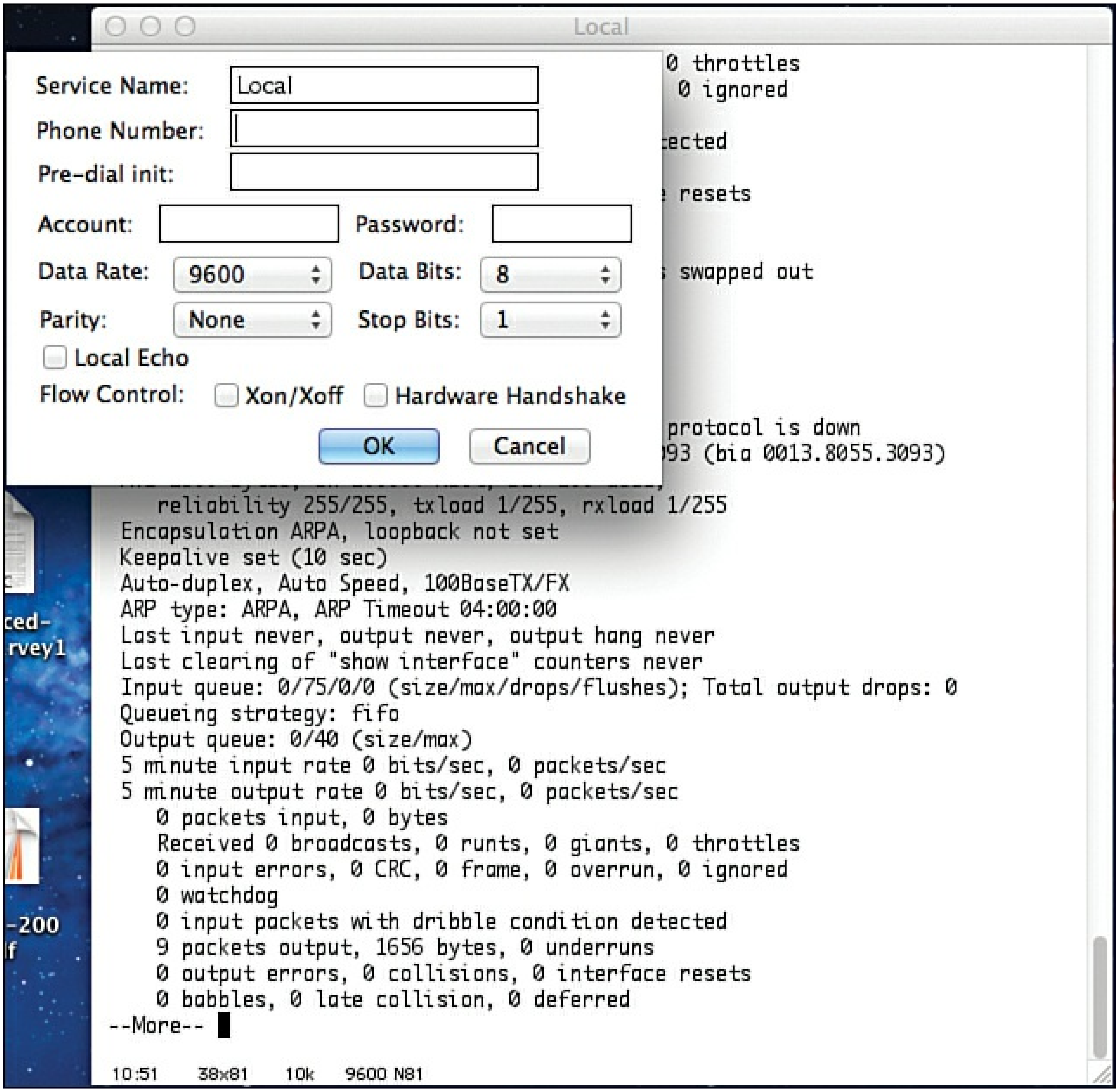
After the PC is physically connected to the console port, a terminal emulator software package must be installed and configured on the PC. The terminal emulator software treats all data as text. It accepts the text typed by the user and sends it over the console connection to the switch. Similarly, any bits coming into the PC over the console connection are displayed as text for the user to read.

The emulator must be configured to use the PC's serial port to match the settings on the switch's console port settings. The default console port settings on a switch are as follows. Note that the last three parameters are referred to collectively as "8N1":

Key Topic

- 9600 bits/second
- No hardware flow control
- 8-bit ASCII
- No parity bits
- 1 stop bit

Figure 7-5 shows one such terminal emulator, Zterm Pro. The image shows the window created by the emulator software in the background, with some output of a **show** command. The foreground, in the upper left, shows a settings window that lists the default console settings as listed just before this paragraph.



Service Name: Local
Phone Number:
Pre-dial init:
Account:
Password:
Data Rate: 9600
Data Bits: 8
Parity: None
Stop Bits: 1
☐ Local Echo
Flow Control: ☐ Xon/Xoff ☐ Hardware Handshake

```
                                                 0 throttles
                                                  0 ignored

                                                ected

                                                 resets

                                                 swapped out





                                                 protocol is down
                                                93 (bia 0013.8055.3093)

     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation ARPA, loopback not set
  Keepalive set (10 sec)
  Auto-duplex, Auto Speed, 100BaseTX/FX
  ARP type: ARPA, ARP Timeout 04:00:00
  Last input never, output never, output hang never
  Last clearing of "show interface" counters never
  Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
  Queueing strategy: fifo
  Output queue: 0/40 (size/max)
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
     0 packets input, 0 bytes
     Received 0 broadcasts, 0 runts, 0 giants, 0 throttles
     0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored
     0 watchdog
     0 input packets with dribble condition detected
     9 packets output, 1656 bytes, 0 underruns
     0 output errors, 0 collisions, 0 interface resets
     0 babbles, 0 late collision, 0 deferred
--More--

10:51    38x81    10k    9600 N81
```

Figure 7-5. Terminal Settings for Console Access

Accessing the CLI with Telnet and SSH

The TCP/IP Telnet application allows a terminal emulator to communicate with another willing device. The process works much like what happens with an emulator on a PC connected to the console, except that the data flows over a TCP/IP network, instead of over a console cable. However, Telnet uses an IP network to send and receive the data, rather than a specialized cable and physical port on the device. The Telnet application protocols call the terminal emulator a *Telnet client* and the device that listens for commands and replies to them a *Telnet server*. Telnet is a TCP-based application layer protocol that uses well-known port 23.

To use Telnet, the user must install a Telnet client software package on his or her PC. (As mentioned earlier, most terminal emulator software packages today include both Telnet and SSH client functions.) The switch runs Telnet server software by default, but the switch does need to have an IP address configured so that it can send and receive IP packets. (Chapter 8, "Configuring Ethernet Switching," covers switch IP address configuration in greater detail.) Additionally, the network between the PC and switch needs to be up and working so that the PC and switch can exchange IP packets.

Many network engineers habitually use a Telnet client to monitor switches. The engineer can sit at his or her desk without having to walk to another part of the building—or go to another state or country—and still get into the CLI of that device.

While Telnet works well, many network engineers instead use *Secure Shell (SSH)* to overcome a serious security problem with Telnet. Telnet sends all data (including any username and password for login to the switch) as clear-text data. SSH encrypts the contents of all messages, including the passwords, avoiding the possibility of someone capturing packets in the network and stealing the password to network devices.

Secure Shell (SSH) does the same basic things as Telnet, but with added security. The user uses a terminal emulator that supports SSH. Like Telnet, SSH uses TCP, using well-known port 22 instead of Telnet's 23. As with Telnet, the SSH server (on the switch) receives the text from each SSH client, processes the text as a command, and sends messages back to the client.

Password Security for CLI Access

A Cisco switch, with default settings, remains relatively secure when locked inside a wiring closet, because by default, a switch allows console access only. However, when you enable Telnet and/or SSH access, you need to enable password security so that only authorized people have access to the CLI. Also, just to be safe, you should password-protect the console as well.

To add basic password checking for the console and for Telnet, the engineer needs to configure a couple of basic commands. The configuration process is covered a little later in this chapter, but you can get a general idea of the commands by looking in the last column of Table 7-3. The table lists the two commands that configure the console and vty passwords (used by Telnet users). After it is configured, the switch supplies a simple password prompt (as a result of the **login** command), and the switch expects the user to enter the password listed in the **password** command.

Table 7-3. CLI Password Configuration: Console and Telnet

Access From	Password Type	Sample Configuration
Console	Console password	line console 0 login password faith
Telnet	vty password	line vty 0 15 login password love

Cisco switches refer to the console as a console line—specifically, console line 0. Similarly, switches support 16 concurrent Telnet sessions, referenced as virtual terminal (vty) lines 0 through 15. (The term *vty* refers to an old name for terminal emulators.) The **line vty 0 15** configuration command tells the switch that the commands that follow apply to all 16 possible concurrent virtual terminal connections to the switch (0 through 15), which includes Telnet as well as SSH access.

After adding the configuration shown in Table 7-3, a user connecting to the console would be prompted for a password, and he or she would have to supply the word **faith** in this case. New Telnet users would also be prompted for a password, with **love** being the required password. Also, with this configuration, no username is required—just a simple password.

Configuring SSH requires a little more effort than the console and Telnet password configuration examples shown in Table 7-3. SSH uses public key cryptography to exchange a shared session key, which in turn is used for encryption. Additionally, SSH requires slightly better login security, requiring at least a password and a username. The section "Configuring Usernames and Secure Shell (SSH)" in Chapter 8 shows the configuration steps and a sample configuration to support SSH.

User and Enable (Privileged) Modes

All three CLI access methods covered so far (console, Telnet, and SSH) place the user in an area of the CLI called *user EXEC mode*. User EXEC mode, sometimes also called *user mode*, allows the user to look around but not break anything. The "EXEC mode" part of the name refers to the fact that in this mode, when you enter a command, the switch executes the command and then displays messages that describe the command's results.

Cisco IOS supports a more powerful EXEC mode called *enable* mode (also known as *privileged* mode or *privileged EXEC* mode). Enable mode gets its name from the **enable** command, which moves the user from user mode to enable mode, as shown in Figure 7-6. The other name for this mode, privileged mode, refers to the fact that powerful (or privileged) commands can be executed there. For example, you can use the **reload** command, which tells the switch to reinitialize or reboot Cisco IOS, only from enable mode.

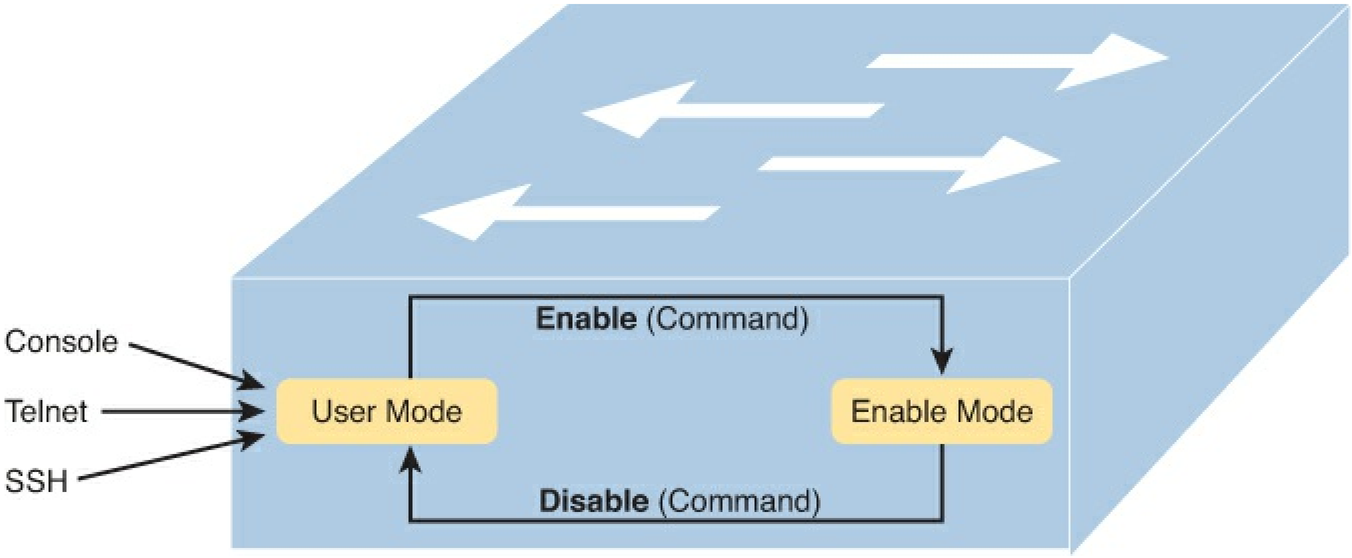


Figure 7-6. User and Privileged Modes

> **Note**
>
> If the command prompt lists the host name followed by a >, the user is in user mode; if it is the host name followed by the #, the user is in enable mode.

Example 7-1 shows the output that you could see in a Telnet window. In this case, the user connects with Telnet and tries the **reload** command. The **reload** command tells the switch to reinitialize or reboot Cisco IOS. IOS allows this powerful command to be used only from enable mode, so in the example, IOS rejects the **reload** command when used in user mode and accepts the command when the user is in enable mode.

Example 7-1. Navigating Between Different EXEC Modes on Switch Certskills1

Click here to view code image

```
Press RETURN to get started.

User Access Verification

Password:
Certskills1>
Certskills1> reload
Translating "reload"
% Unknown command or computer name, or unable to find computer address
Certskills1> enable
Password:
Certskills1#
Certskills1# reload

Proceed with reload? [confirm] y
00:08:42: %SYS-5-RELOAD: Reload requested by console. Reload Reason: Reload Command.
```

> **Note**
>
> The commands that can be used in either user (EXEC) mode or enable (EXEC) mode are called EXEC commands.

This example is the first instance of this book showing you the output from the CLI, so it is worth noting a few conventions. The bold text represents what the user typed, while the nonbold text is what the switch sent back to the terminal emulator. Also, the typed passwords do not show up on the screen for security purposes. Finally, note that this switch has been preconfigured with a host name of "Certskills1," so the command prompt on the left shows that host name on each line.

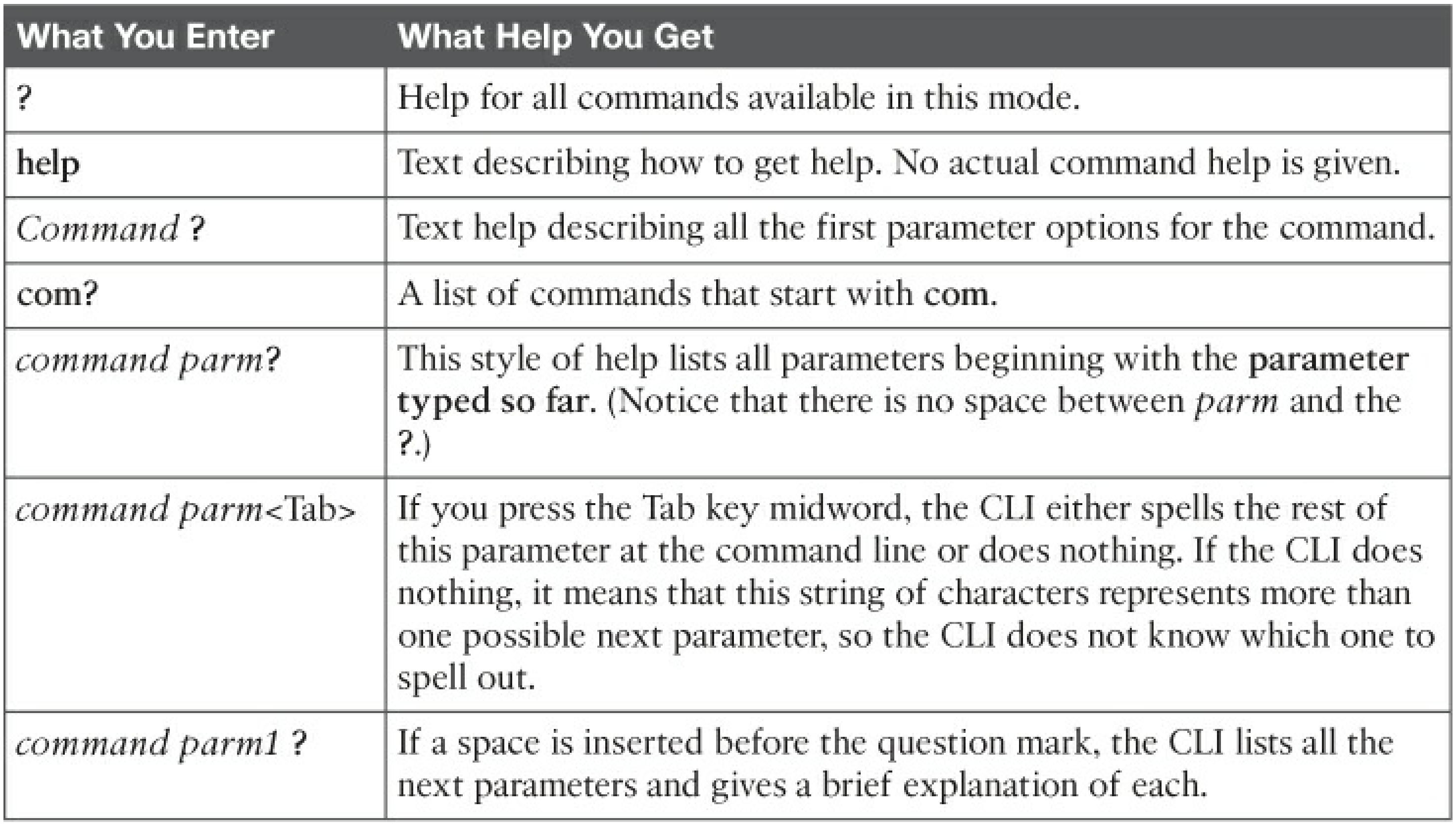
So far, this chapter has pointed out some of the first things you should know when unpacking and installing a switch. The switch will work without any configuration—just plug in the power and Ethernet cables, and it works. However, you should at least connect to the switch console port and configure passwords for the console, Telnet, SSH, and the enable secret password. Next, this chapter examines some of the CLI features that exist regardless of how you access the CLI.

CLI Help Features

If you printed the Cisco IOS Command Reference documents, you would end up with a stack of paper several feet tall. No one should expect to memorize all the commands—and no one does. You can use several very easy, convenient tools to help remember commands and save time typing. As you progress through your Cisco certifications, the exams will cover progressively more commands. However, you should know the methods of getting command help.

Table 7-4 summarizes command-recall help options available at the CLI. Note that, in the first column, *command* represents any command. Likewise, *parm* represents a command's parameter. For example, the third row lists *command* **?**, which means that commands such as **show ?** and **copy ?** would list help for the **show** and **copy** commands, respectively.

Table 7-4. Cisco IOS Software Command Help



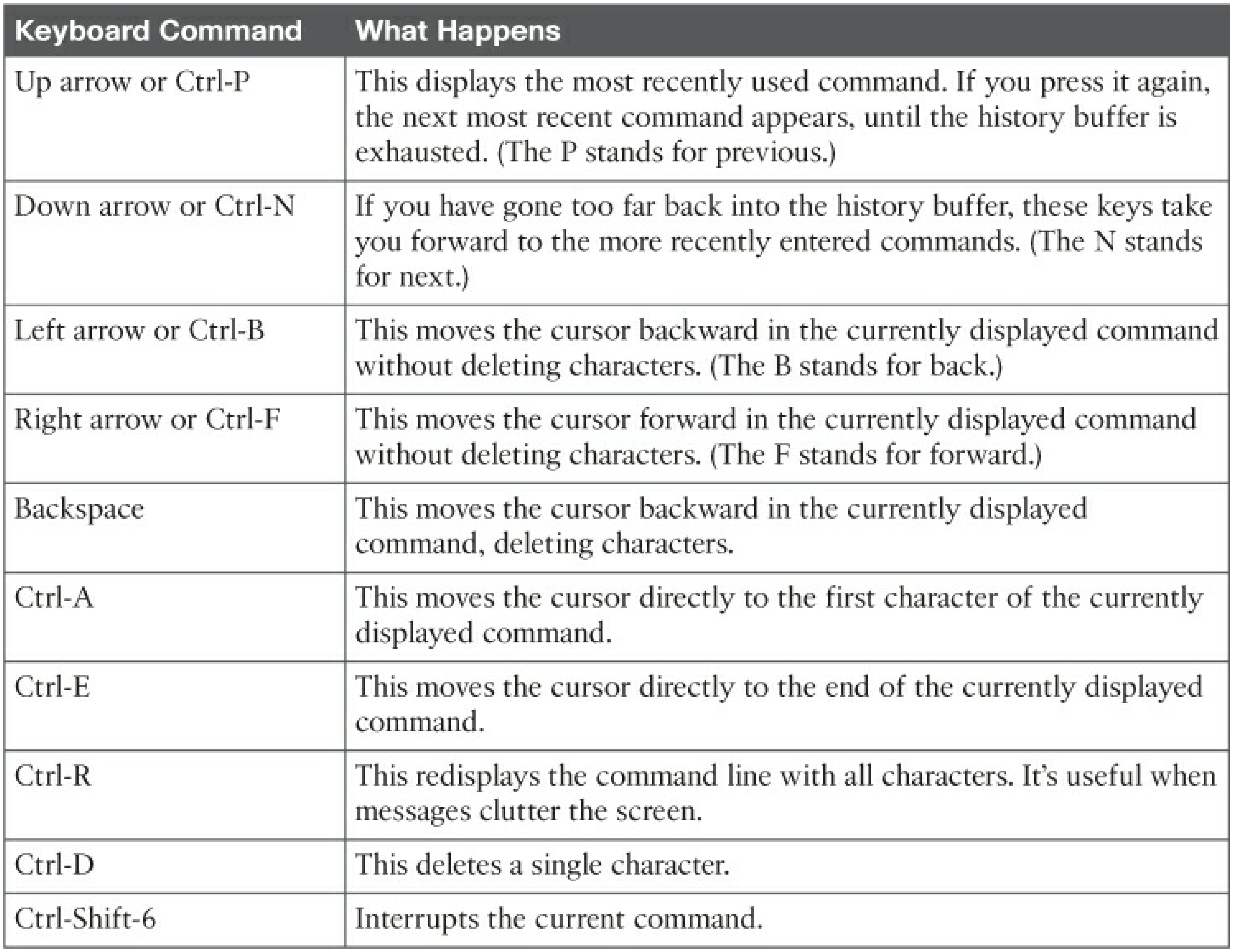
What You Enter	What Help You Get
?	Help for all commands available in this mode.
help	Text describing how to get help. No actual command help is given.
Command ?	Text help describing all the first parameter options for the command.
com?	A list of commands that start with **com**.
command parm?	This style of help lists all parameters beginning with the **parameter typed so far.** (Notice that there is no space between *parm* and the ?.)
command parm<Tab>	If you press the Tab key midword, the CLI either spells the rest of this parameter at the command line or does nothing. If the CLI does nothing, it means that this string of characters represents more than one possible next parameter, so the CLI does not know which one to spell out.
command parm1 ?	If a space is inserted before the question mark, the CLI lists all the next parameters and gives a brief explanation of each.

When you enter the **?**, the Cisco IOS CLI reacts immediately; that is, you don't need to press the Enter key or any other keys. The device running Cisco IOS also redisplays what you entered before the **?** to save you some keystrokes. If you press Enter immediately after the **?**, Cisco IOS tries to execute the command with only the parameters you have entered so far.

The information supplied by using help depends on the CLI mode. For example, when **?** is entered in user mode, the commands allowed in user mode are displayed, but commands available only in enable mode (not in user mode) are not displayed. Also, help is available in configuration mode, which is the mode used to configure the switch. In fact, configuration mode has many different subconfiguration modes, as explained in the section "Configuration Submodes and Contexts," later in this chapter. So, you can get help for the commands available in each configuration submode as well. (Note that this might be a good time to use the free NetSim Lite product on the DVD—open any lab, use the question mark, and try some commands.)

Cisco IOS stores the commands that you enter in a history buffer, storing ten commands by default. The CLI allows you to move backward and forward in the historical list of commands and then edit the command before reissuing it. These key sequences can help you use the CLI more quickly on the exams. Table 7-5 lists the commands used to manipulate previously entered commands.

Table 7-5. Key Sequences for Command Edit and Recall



Keyboard Command	What Happens
Up arrow or Ctrl-P	This displays the most recently used command. If you press it again, the next most recent command appears, until the history buffer is exhausted. (The P stands for previous.)
Down arrow or Ctrl-N	If you have gone too far back into the history buffer, these keys take you forward to the more recently entered commands. (The N stands for next.)
Left arrow or Ctrl-B	This moves the cursor backward in the currently displayed command without deleting characters. (The B stands for back.)
Right arrow or Ctrl-F	This moves the cursor forward in the currently displayed command without deleting characters. (The F stands for forward.)
Backspace	This moves the cursor backward in the currently displayed command, deleting characters.
Ctrl-A	This moves the cursor directly to the first character of the currently displayed command.
Ctrl-E	This moves the cursor directly to the end of the currently displayed command.
Ctrl-R	This redisplays the command line with all characters. It's useful when messages clutter the screen.
Ctrl-D	This deletes a single character.
Ctrl-Shift-6	Interrupts the current command.

The debug and show Commands

By far, the single most popular Cisco IOS command is the **show** command. The **show** command has a large variety of options, and with those options, you can find the status of almost every feature of Cisco IOS. Essentially, the **show** command lists the currently known facts about the switch's operational status. The only work the switch does in reaction to **show** commands is to find the current status and list the information in messages sent to the user.

The **debug** command has a similar role as compared with the **show** command. Like the **show** command, **debug** has many options. However, instead of just listing messages about the current status, the **debug** command asks the switch to continue monitoring different processes in the switch. The switch then sends ongoing messages to the user when different events occur.

The effects of the **show** and **debug** commands can be compared to a photograph (**show** command) and a movie (**debug** command). A **show** command shows what's true at a single point in time, and it takes less effort. A **debug** command shows what's true over time, but it requires more effort. As a result, the **debug** command requires more CPU cycles, but it lets you watch what is happening in a switch while it is happening.

Cisco IOS handles the messages from the **show** and **debug** commands very differently. IOS sends the output of **show** commands to the user that issued the **show** command, and to no other users. However, IOS reacts to **debug** commands by creating log messages related to that **debug** command's options. Any user logged in can choose to view the log messages, just by using the **terminal monitor** command from enable mode.

IOS also treats the **show** command as a very short-lived event and the **debug** command as an ongoing task. The options enabled by a single **debug** command are not disabled until the user takes action or until the switch is reloaded. A **reload** of the switch disables all currently enabled debug options. To disable a single debug option, repeat the same **debug** command with those options, prefaced by the word **no**. For example, if the **debug spanning-tree** command had been issued earlier, issue the **no debug spanning-tree** command to disable that same debug. Also, the **no debug all** and **undebug all** commands disable all currently enabled debugs.

Be aware that some **debug** options create so many messages that Cisco IOS cannot process them all, possibly resulting in a crash of Cisco IOS. You might want to check the current switch CPU utilization with the **show process** command before issuing any **debug** command. To be more careful, before enabling an unfamiliar **debug** command option, issue a **no debug all** command and then issue the **debug** that you want to use. Then quickly retrieve the **no debug all** command using the up arrow or Ctrl-P key sequence twice. If the debug quickly degrades switch performance, the switch might be too busy to listen to what you are typing. The process described in this paragraph saves a bit of typing and can be the difference between preventing the switch from failing or not.

Configuring Cisco IOS Software

You must understand how to configure a Cisco switch to succeed on the exam and in real networking jobs. This section covers the basic configuration processes, including the concept of a configuration file and the locations in which the configuration files can be stored. Although this section focuses on the configuration process, and not on the configuration commands themselves, you should know all the commands covered in this chapter for the exams, in addition to the configuration processes.

Configuration mode is another mode for the Cisco CLI, similar to user mode and privileged mode. User mode lets you issue nondisruptive commands and displays some information. Privileged mode supports a superset of commands compared to user mode, including commands that might harm the switch. However, none of the commands in user or privileged mode changes the switch's configuration. Configuration mode accepts *configuration commands*—commands that tell the switch the details of what to do and how to do it. Figure 7-7 illustrates the relationships among configuration mode, user EXEC mode, and privileged EXEC mode.

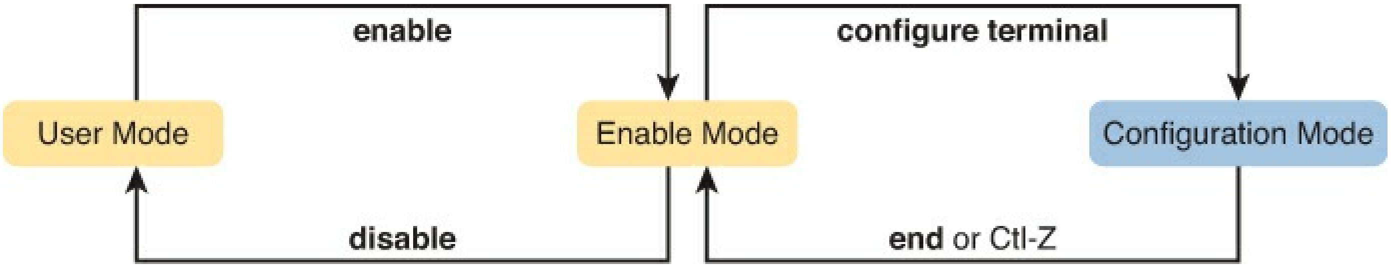


Figure 7-7. CLI Configuration Mode Versus EXEC Modes

Commands entered in configuration mode update the active configuration file. *These changes to the configuration occur immediately each time you press the Enter key at the end of a command.* Be careful when you enter a configuration command!

Configuration Submodes and Contexts

Configuration mode itself contains a multitude of subcommand modes. *Context-setting commands* move you from one configuration subcommand mode, or context, to another. These context-setting commands tell the switch the topic about which you will enter the next few configuration commands. More importantly, the context tells the switch the topic you care about right now, so when you use the **?** to get help, the switch gives you help about that topic only.

> **Note**
>
> *Context-setting* is not a Cisco term—it's just a term used here to help make sense of configuration mode.

The **interface** command is one of the most commonly used context-setting configuration commands. For example, the CLI user could enter interface configuration mode by entering the **interface FastEthernet 0/1** configuration command. Asking for help in interface configuration mode displays only commands that are useful when configuring Ethernet interfaces. Commands used in this context are called *subcommands*—or, in this specific case, *interface subcommands*. When you begin practicing with the CLI with real equipment, the navigation between modes can become natural. For now, consider Example 7-2, which shows the following:

- Movement from enable mode to global configuration mode by using the **configure terminal** EXEC command
- Using a **hostname Fred** global configuration command to configure the switch's name
- Movement from global configuration mode to console line configuration mode (using the **line console 0** command)
- Setting the console's simple password to **hope** (using the **password hope** line subcommand)
- Movement from console configuration mode to interface configuration mode (using the **interface** command)
- Setting the speed to 100 Mbps for interface Fa0/1 (using the **speed 100** interface subcommand)
- Movement from interface configuration mode back to global configuration mode (using the **exit** command)

Example 7-2. Navigating Between Different Configuration Modes

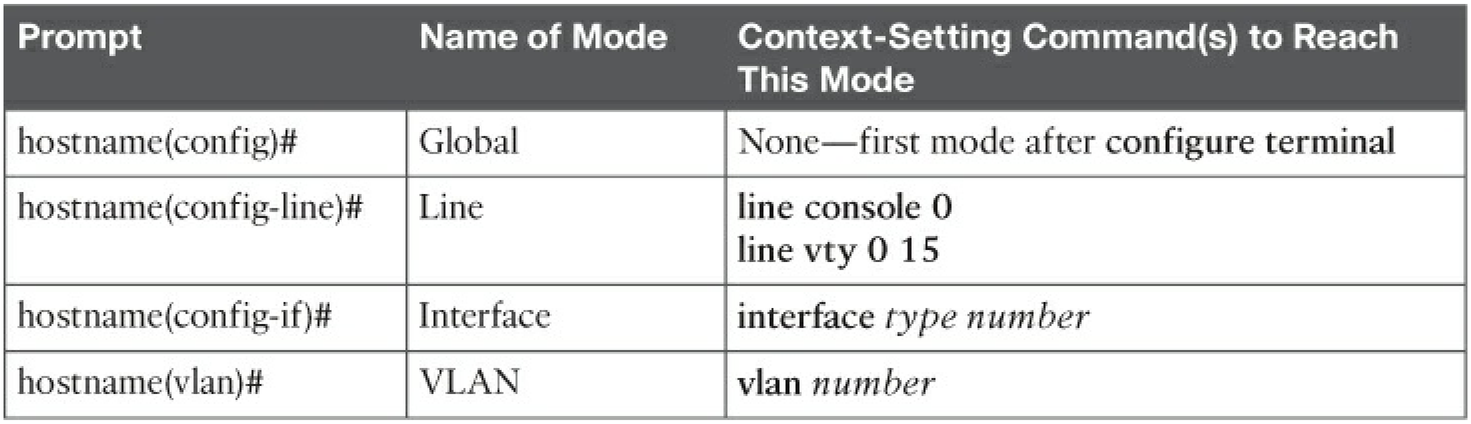
Click here to view code image

```
Switch# configure terminal
Switch(config)# hostname Fred
Fred(config)# line console 0
Fred(config-line)# password hope
Fred(config-line)# interface FastEthernet 0/1
Fred(config-if)# speed 100
Fred(config-if)# exit
Fred(config)#
```

The text inside parentheses in the command prompt identifies the configuration mode. For example, the first command prompt after you enter configuration mode lists (config), meaning global configuration mode. After the **line console 0** command, the text expands to (config-line), meaning line configuration mode. Table 7-6 shows the most common command prompts in configuration mode, the names of those modes, and the context-setting commands used to reach those modes.

Key Topic

Table 7-6. Common Switch Configuration Modes



Prompt	Name of Mode	Context-Setting Command(s) to Reach This Mode
hostname(config)#	Global	None—first mode after **configure terminal**
hostname(config-line)#	Line	**line console 0** **line vty 0 15**
hostname(config-if)#	Interface	**interface** *type number*
hostname(vlan)#	VLAN	**vlan** *number*

You should practice until you become comfortable moving between the different configuration modes, back to enable mode, and then back into the configuration modes. However, you can learn these skills just doing labs about the topics in later chapters of the book. For now, Figure 7-8 shows most of the navigation between global configuration mode and the four configuration submodes listed in Table 7-6.

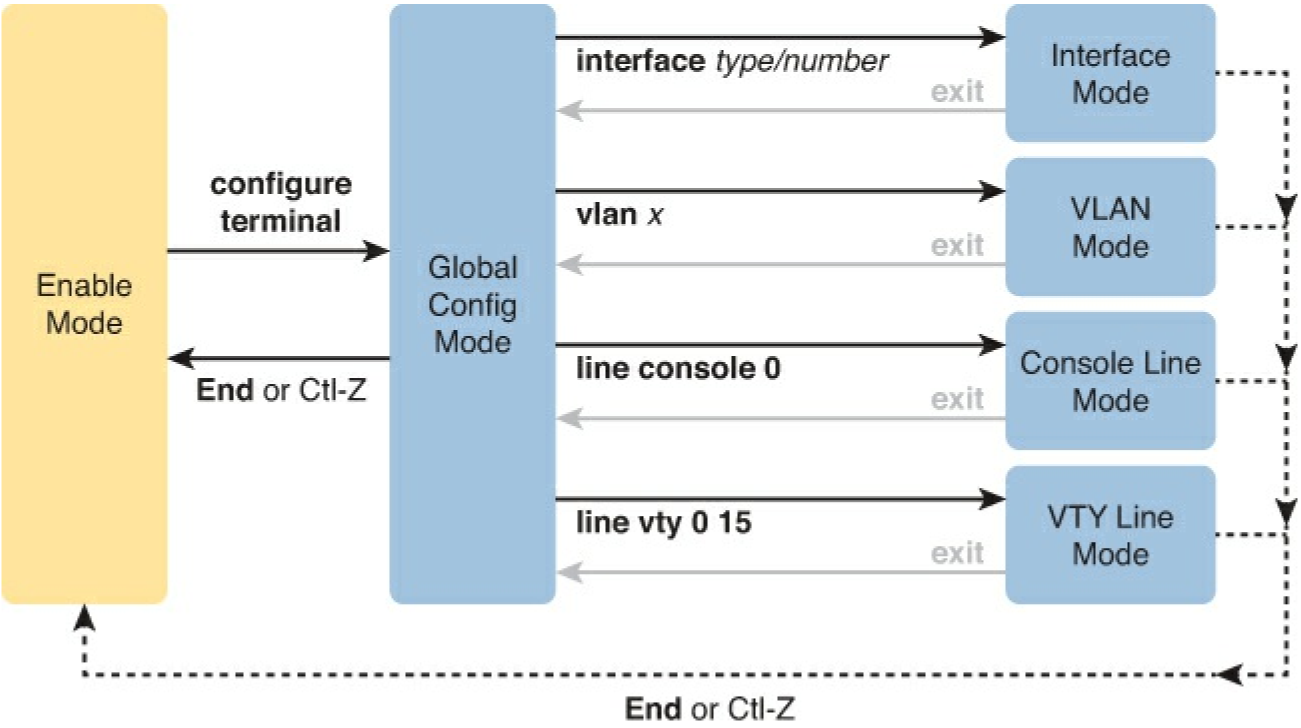


Figure 7-8. Navigation In and Out of Switch Configuration Modes

> **Note**
>
> You can also move directly from one configuration submode to another, without first using the **exit** command to move back to global configuration mode. Just use the commands listed in bold in the center of the figure.

No set rules exist for what commands are global commands or subcommands. Generally, however, when multiple instances of a parameter can be set in a single switch, the command used to set the parameter is likely a configuration subcommand. Items that are set once for the entire switch are likely global commands. For example, the **hostname** command is a global command because there is only one host name per switch. Conversely, the **duplex** command is an interface subcommand to allow the switch to use a different setting on the different interfaces.

Storing Switch Configuration Files

When you configure a switch, it needs to use the configuration. It also needs to be able to retain the configuration in case the switch loses power. Cisco switches contain random-access memory (RAM) to store data while Cisco IOS is using it, but RAM loses its contents when the switch loses power. To store information that must be retained when the switch loses power, Cisco switches use several types of more permanent memory, none of which has any moving parts. By avoiding components with moving parts (such as traditional disk drives), switches can maintain better uptime and availability.

The following list details the four main types of memory found in Cisco switches, as well as the most common use of each type:

- **RAM:** Sometimes called DRAM, for dynamic random-access memory, RAM is used by the switch just as it is used by any other computer: for working storage. The running (active) configuration file is stored here.
- **ROM:** Read-only memory (ROM) stores a bootstrap (or boothelper) program that is loaded when the switch first powers on. This bootstrap program then finds the full Cisco IOS image and manages the process of loading Cisco IOS into RAM, at which point Cisco IOS takes over operation of the switch.
- **Flash memory:** Either a chip inside the switch or a removable memory card, flash memory stores fully functional Cisco IOS images and is the default location where the switch gets its Cisco IOS at boot time. Flash memory also can be used to store any other files, including backup copies of configuration files.
- **NVRAM:** Nonvolatile RAM (NVRAM) stores the initial or startup configuration file that is used when the switch is first powered on and when the switch is reloaded.

Figure 7-9 summarizes this same information in a briefer and more convenient form for memorization and study.

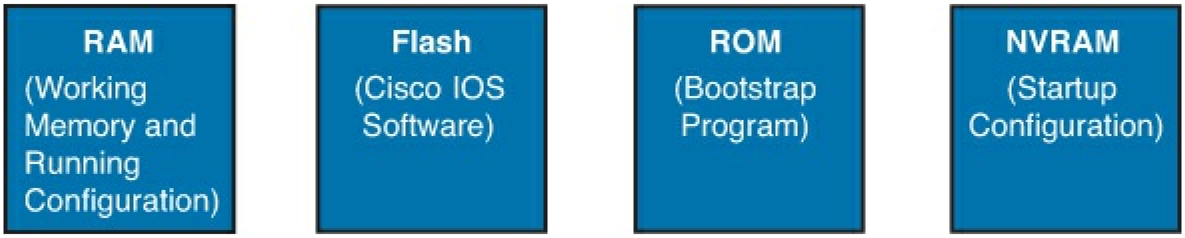
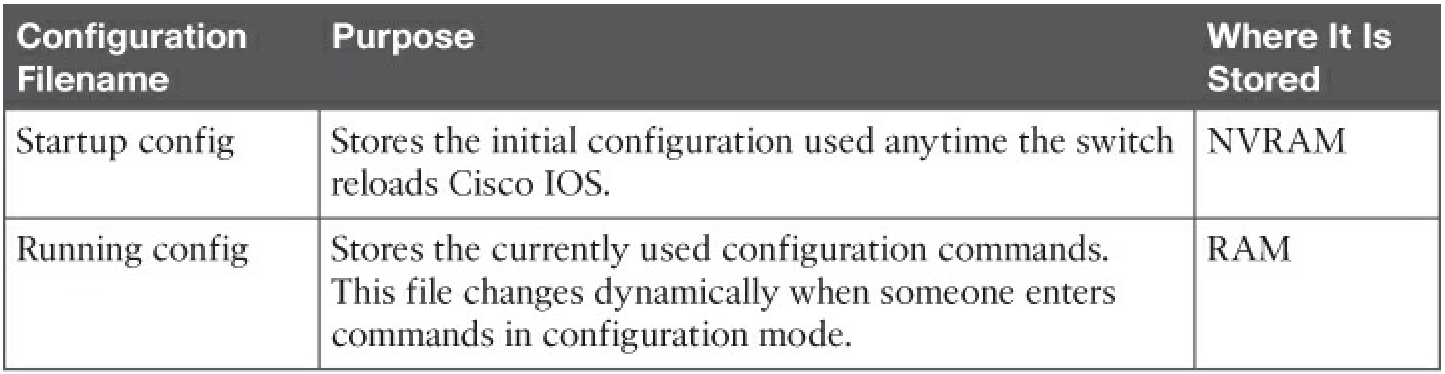


Figure 7-9. Cisco Switch Memory Types

Cisco IOS stores the collection of configuration commands in a *configuration file*. In fact, switches use multiple configuration files—one file for the initial configuration used when powering on, and another configuration file for the active, currently used running configuration as stored in RAM. Table 7-7 lists the names of these two files, their purpose, and their storage location.

Table 7-7. Names and Purposes of the Two Main Cisco IOS Configuration Files



Configuration Filename	Purpose	Where It Is Stored
Startup config	Stores the initial configuration used anytime the switch reloads Cisco IOS.	NVRAM
Running config	Stores the currently used configuration commands. This file changes dynamically when someone enters commands in configuration mode.	RAM

Essentially, when you use configuration mode, you change only the running config file. This means that the configuration example earlier in this chapter (Example 7-2) updates only the running config file. However, if the switch lost power right after that example, all that configuration would be lost. If you want to keep that configuration, you have to copy the running config file into NVRAM, overwriting the old startup config file.

Example 7-3 demonstrates that commands used in configuration mode change only the running configuration in RAM. The example shows the following concepts and steps:

Step 1. The original **hostname** command on the switch, with the startup config file matching the running config file.

Step 2. The **hostname** command changes the host name, but only in the running config file.

Step 3. The **show running-config** and **show startup-config** commands are shown, with only the **hostname** commands displayed for brevity, to make the point that the two configuration files are now different.

Example 7-3. How Configuration Mode Commands Change the Running Config File, Not the Startup Config File

[Click here to view code image](#)

```
! Step 1 next (two commands)
!
hannah# show running-config
! (lines omitted)
hostname hannah
! (rest of lines omitted)

hannah# show startup-config
! (lines omitted)
hostname hannah
! (rest of lines omitted)
! Step 2 next. Notice that the command prompt changes immediately after
! the hostname command.
hannah# configure terminal
hannah(config)# hostname jessie
jessie(config)# exit
! Step 3 next (two commands)
!
jessie# show running-config
! (lines omitted)
hostname jessie
! (rest of lines omitted - notice that the running configuration reflects the
! changed hostname)
jessie# show startup-config
! (lines omitted)
hostname hannah
! (rest of lines omitted - notice that the changed configuration is not
! shown in the startup config)
```

Note

Cisco uses the term *reload* to refer to what most PC operating systems call rebooting or restarting. In each case, it is a reinitialization of the software. The **reload** EXEC command causes a switch to reload.

Copying and Erasing Configuration Files

If you want to keep the new configuration commands you add in configuration mode (so that the changes are present the next time the system is rebooted), like the **hostname jessie** command in [Example 7-3](#), you need to use the command **copy running-config startup-config**. This command overwrites the current startup config file with what is currently in the running configuration file.

The **copy** command can be used to copy files in a switch, most typically a configuration file or a new version of Cisco IOS Software. The most basic method for moving configuration files in and out of a switch is to use the **copy** command to copy files between RAM or NVRAM on a switch and a TFTP server. The files can be copied between any pair, as shown in [Figure 7-10](#).

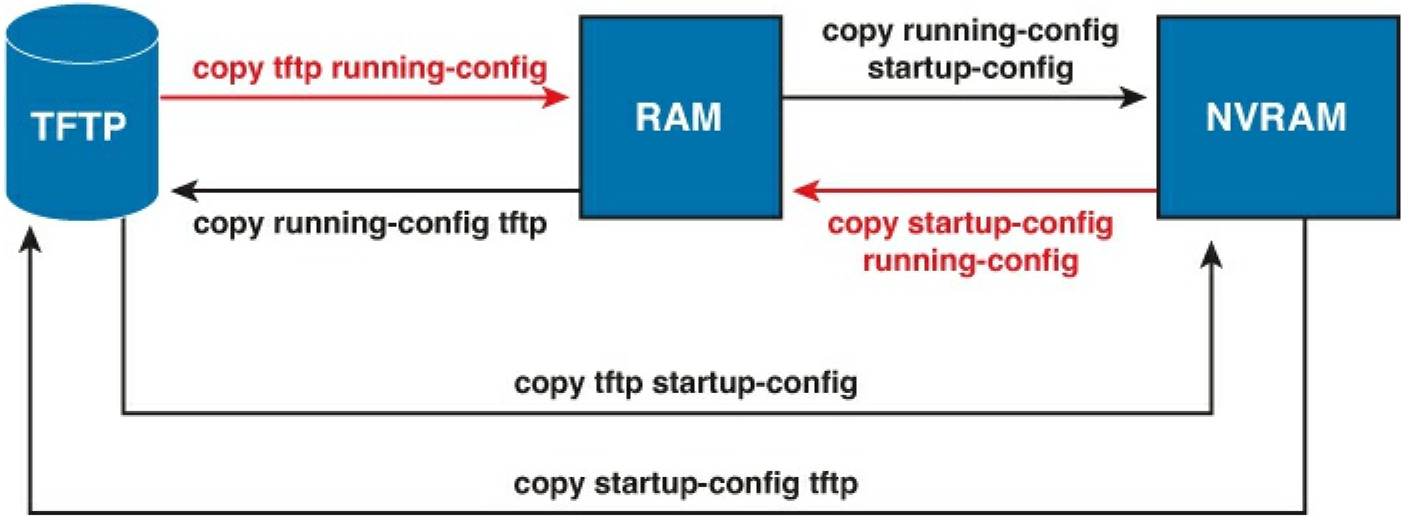


Figure 7-10. Locations for Copying and Results from Copy Operations

The commands for copying Cisco IOS configurations can be summarized as follows:

```
copy {tftp | running-config | startup-config} {tftp | running-config | startup-config}
```

The first set of parameters enclosed in braces ({ }) is the "from" location; the next set of parameters is the "to" location.

The **copy** command always replaces the existing file when the file is copied into NVRAM or into a TFTP server. In other words, it acts as if the destination file was erased and the new file completely replaced the old one. However, when the **copy** command copies a configuration file into the running config file in RAM, the configuration file in RAM is not replaced, but is merged instead. Effectively, any **copy** into RAM works just as if you entered the commands in the "from" configuration file in the order listed in the config file.

Who cares? Well, we do. If you change the running config and then decide that you want to revert to what's in the startup config file, the result of the **copy startup-config running-config** command might not cause the two files to actually match. One way to guarantee that the two configuration files match is to issue the **reload** command, which reloads, or reboots, the switch, which erases RAM and then copies the startup config into RAM as part of the reload process.

You can use three different commands to erase the contents of NVRAM. The **write erase** and **erase startup-config** commands are older, whereas the **erase nvram:** command is the more recent, and recommended, command. All three commands simply erase the contents of the NVRAM configuration file. Of course, if the switch is reloaded at this point, there is no initial configuration. Note that Cisco IOS does not have a command that erases the contents of the running config file. To clear out the running config file, simply erase the startup config file and then **reload** the switch.

> **Note**
>
> Making a copy of all current switch and router configurations should be part of any network's overall security strategy, mainly so that you can replace a device's configuration if an attack changes the configuration.

Initial Configuration (Setup Mode)

Cisco IOS Software supports two primary methods of giving a switch an initial basic configuration—configuration mode, which has already been covered in this chapter, and setup mode. *Setup mode* leads a switch administrator by asking questions that prompt the administrator for basic configuration parameters. After the administrator answers the questions, IOS builds a configuration file, saves it as the startup config, and also loads it as the running config to start using the new configuration.

When a Cisco switch or router initializes, but the startup config file is empty, the switch or router asks the console user if he wants to use setup. Figure 7-11 shows the branches in the process. The left side of the figure, moving down, brings the user to the point at which IOS asks the user questions about what should be added to the configuration.

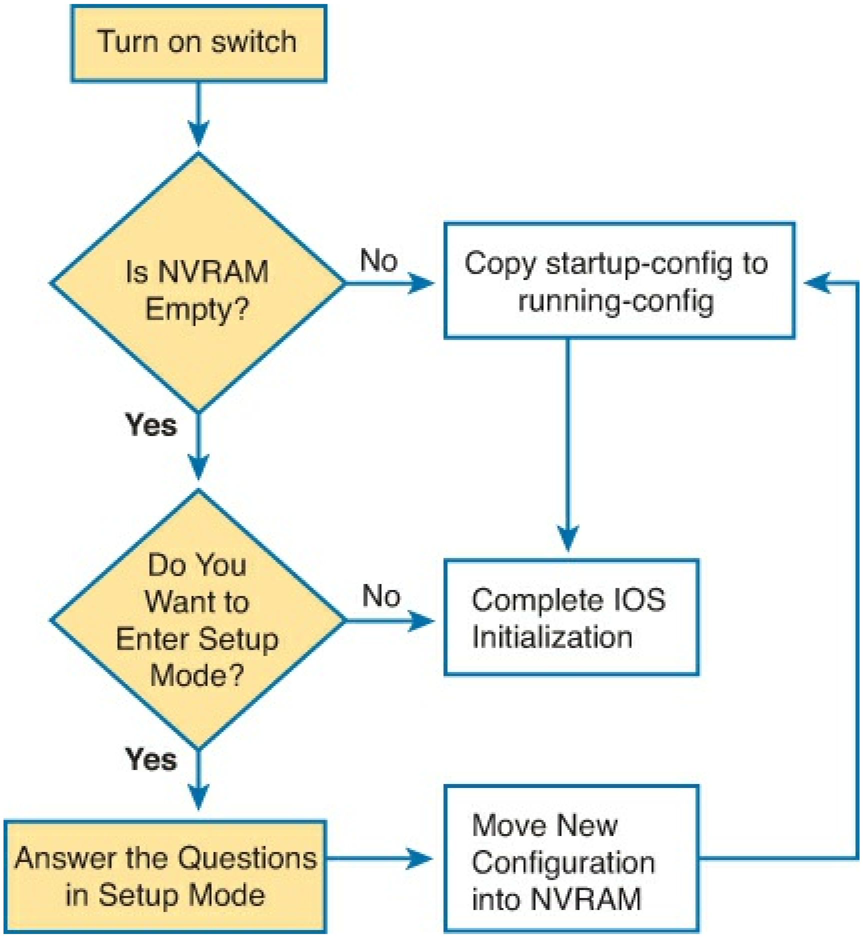

Turn on switch
Is NVRAM Empty?
No
Copy startup-config to running-config
Yes
Do You Want to Enter Setup Mode?
No
Complete IOS Initialization
Yes
Answer the Questions in Setup Mode
Move New Configuration into NVRAM

Figure 7-11. Getting into Setup Mode

Frankly, most network engineers never use setup mode, mainly because setup supports only a small percentage of modern switch configuration settings. However, you will still see some evidence of setup, because when you reload a switch or router that has no configuration, IOS will ask you whether you want to enter the "initial configuration dialogue" (the official term for setup mode). Just answer "no," as shown in Example 7-4, and use configuration mode to configure the device.

Example 7-4. Initial Configuration Dialog (Setup)—Rejected

Click here to view code image

```
--- System Configuration Dialog ---

Would you like to enter the initial configuration dialog? [yes/no]: no

Switch>
```

IOS Version and Other Reload Facts

To finish this first chapter about how Cisco IOS works, with the IOS CLI, this last topic looks at the switch **show version** command.

When a switch loads the IOS, it must do many tasks. The IOS software itself must be loaded into RAM. The IOS must become aware of the hardware available, for example, all the different LAN interfaces on the switch. After the software is loaded, the IOS keeps track of some statistics related to the current operation of the switch, like the amount of time since the IOS was last loaded and the reason why the IOS was most recently loaded.

The **show version** command lists these facts, plus many others. As you might guess from the command itself, the **show version** command does list information about the IOS, including the version of IOS software. However, as highlighted in Example 7-5, it lists many other interesting facts as well.

Example 7-5. Example of a show version **Command on a Cisco Switch**

Click here to view code image

```
SW1# show version
Cisco IOS Software, C2960 Software (C2960-LANBASEK9-M), Version 15.0(1)SE3, RELEASE
SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2012 by Cisco Systems, Inc.
Compiled Wed 30-May-12 14:26 by prod_rel_team

ROM: Bootstrap program is C2960 boot loader
BOOTLDR: C2960 Boot Loader (C2960-HBOOT-M) Version 12.2(44)SE5, RELEASE SOFTWARE (fc1)

SW1 uptime is 2 days, 22 hours, 2 minutes
System returned to ROM by power-on
System image file is "flash:c2960-lanbasek9-mz.150-1.SE3.bin"


This product contains cryptographic features and is subject to United
States and local country laws governing import, export, transfer and
use...
! Lines omitted for brevity

cisco WS-C2960-24TT-L (PowerPC405) processor (revision P0) with 65536K bytes of
memory.
Processor board ID FCQ1621X6QC
Last reset from power-on
1 Virtual Ethernet interface
24 FastEthernet interfaces
2 Gigabit Ethernet interfaces
The password-recovery mechanism is enabled.

64K bytes of flash-simulated non-volatile configuration memory.
Base ethernet MAC Address : 18:33:9D:7B:13:80
Motherboard assembly number : 73-11473-11
Power supply part number : 341-0097-03
Motherboard serial number : FCQ162103ZL
```

```
Power supply serial number : ALD1619B37W
Model revision number : P0
Motherboard revision number : A0
Model number : WS-C2960-24TT-L
System serial number : FCQ1621X6QC
Top Assembly Part Number : 800-29859-06
Top Assembly Revision Number : C0
Version ID : V10
CLEI Code Number : COMCX00ARB
Hardware Board Revision Number : 0x01


Switch Ports Model SW Version SW Image
------ ----- ----- ---------- ----------
* 1 26 WS-C2960-24TT-L 15.0(1)SE3 C2960-LANBASEK9-M


Configuration register is 0xF
```

Working through the highlighted parts of the example, top to bottom, this command lists

- The IOS version
- Time since last load of the IOS
- Reason for last load of the IOS
- Number of Fast Ethernet interfaces (24)
- Number of Gigabit Ethernet interfaces (2)
- Switch model number

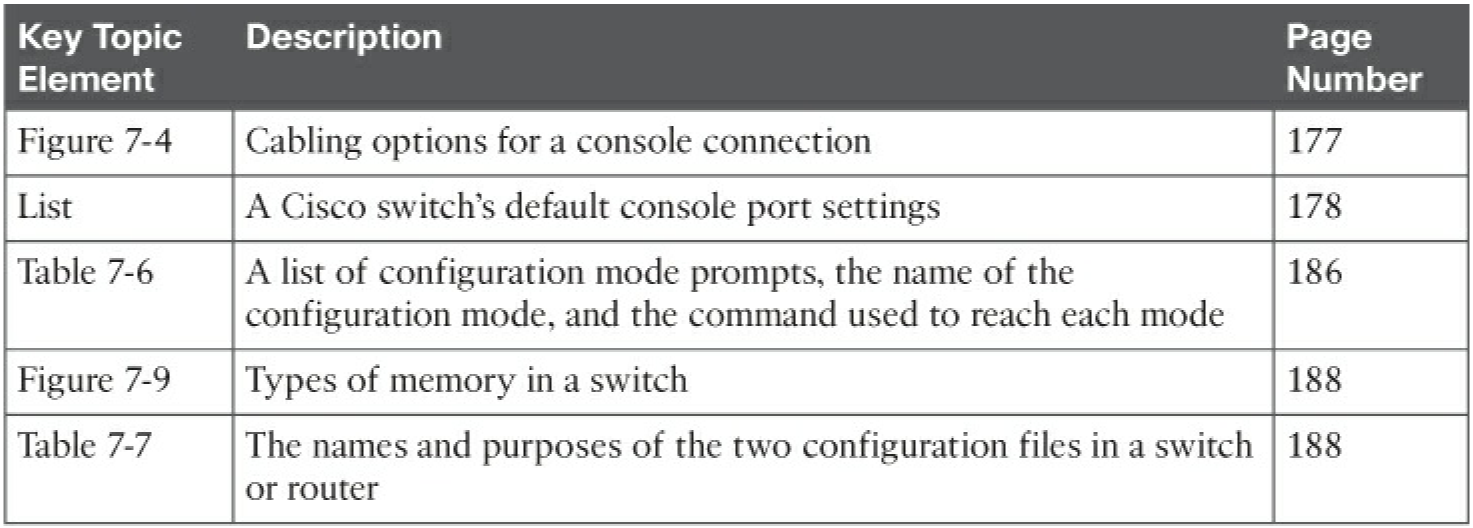
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 7-8 lists these key topics and where each is discussed.

Key Topic

Table 7-8. Key Topics for Chapter 7



Key Topic Element	Description	Page Number
Figure 7-4	Cabling options for a console connection	177
List	A Cisco switch's default console port settings	178
Table 7-6	A list of configuration mode prompts, the name of the configuration mode, and the command used to reach each mode	186
Figure 7-9	Types of memory in a switch	188
Table 7-7	The names and purposes of the two configuration files in a switch or router	188

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists for you to check your work.

Definitions of Key Terms

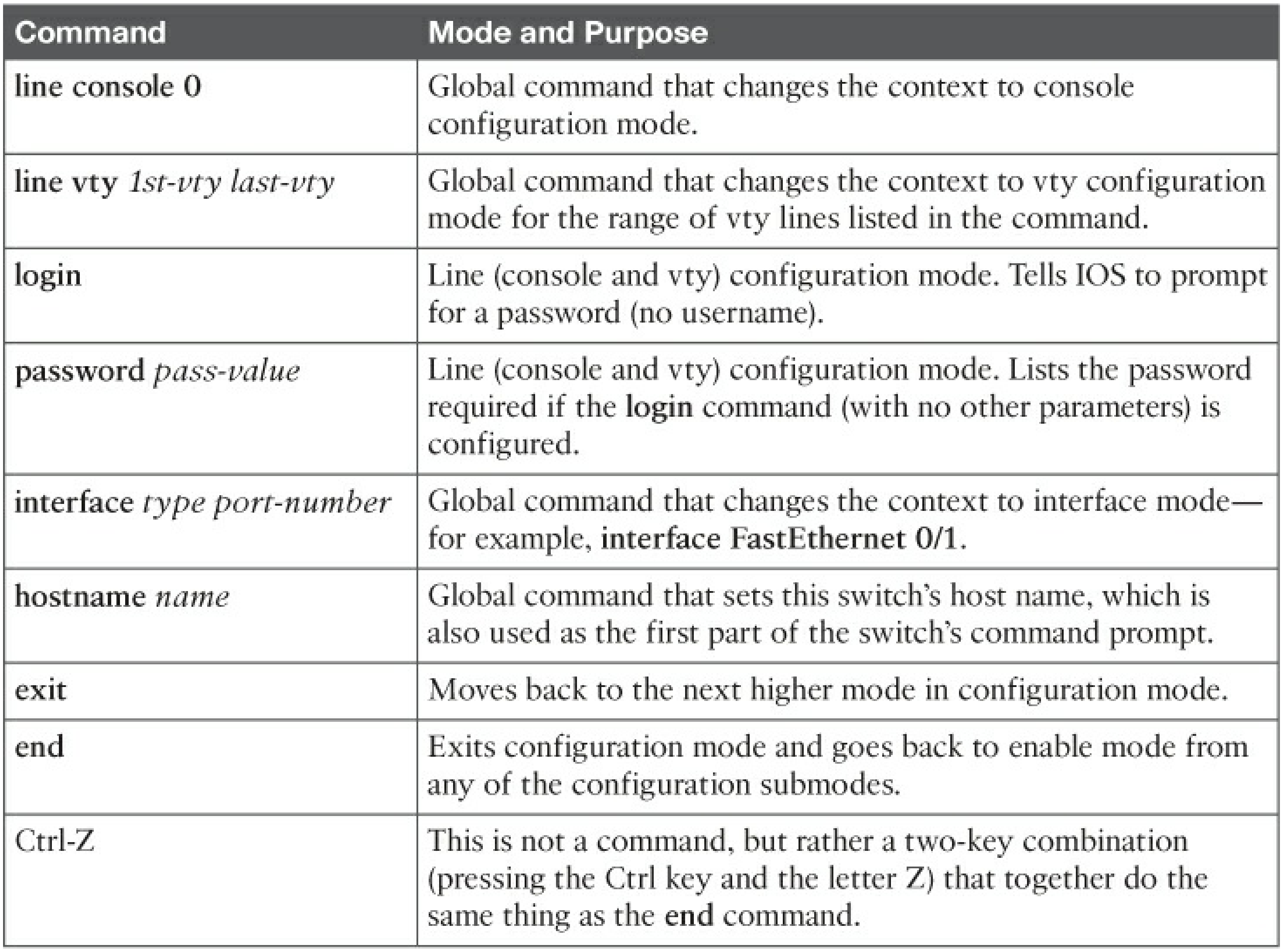
After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

- command-line interface (CLI)
- Telnet
- Secure Shell (SSH)
- enable mode
- user mode
- configuration mode
- startup config file
- running config file

Command References

Table 7-9 lists and briefly describes the configuration commands used in this chapter.

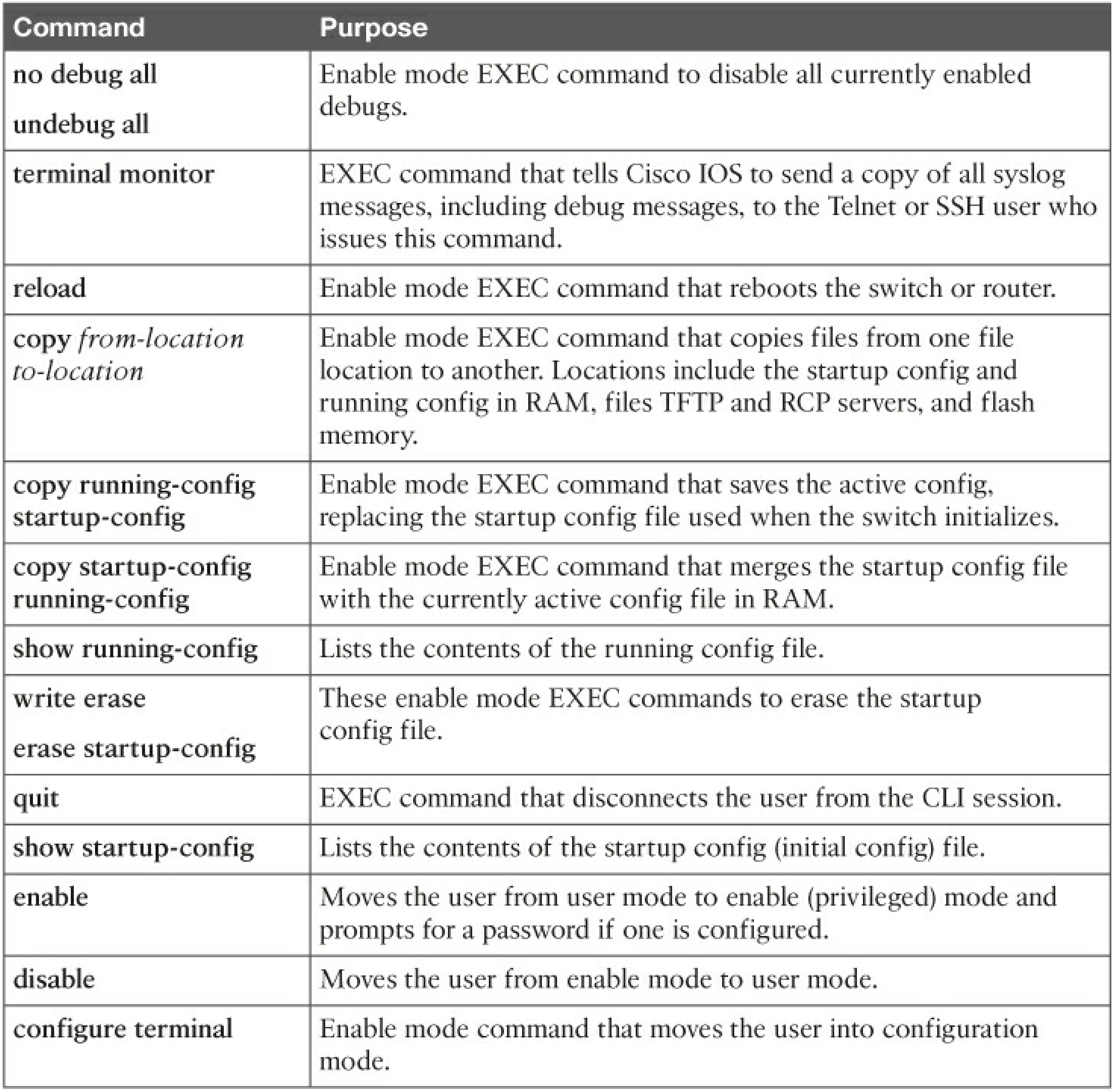
Table 7-9. Chapter 7 Configuration Commands



Command	Mode and Purpose
line console 0	Global command that changes the context to console configuration mode.
line vty *1st-vty last-vty*	Global command that changes the context to vty configuration mode for the range of vty lines listed in the command.
login	Line (console and vty) configuration mode. Tells IOS to prompt for a password (no username).
password *pass-value*	Line (console and vty) configuration mode. Lists the password required if the **login** command (with no other parameters) is configured.
interface *type port-number*	Global command that changes the context to interface mode—for example, **interface FastEthernet 0/1**.
hostname *name*	Global command that sets this switch's host name, which is also used as the first part of the switch's command prompt.
exit	Moves back to the next higher mode in configuration mode.
end	Exits configuration mode and goes back to enable mode from any of the configuration submodes.
Ctrl-Z	This is not a command, but rather a two-key combination (pressing the Ctrl key and the letter Z) that together do the same thing as the **end** command.

Table 7-10 lists and briefly describes the EXEC commands used in this chapter.

Table 7-10. Chapter 7 EXEC Command Reference



Command	Purpose
no debug all **undebug all**	Enable mode EXEC command to disable all currently enabled debugs.
terminal monitor	EXEC command that tells Cisco IOS to send a copy of all syslog messages, including debug messages, to the Telnet or SSH user who issues this command.
reload	Enable mode EXEC command that reboots the switch or router.
copy *from-location to-location*	Enable mode EXEC command that copies files from one file location to another. Locations include the startup config and running config in RAM, files TFTP and RCP servers, and flash memory.
copy running-config startup-config	Enable mode EXEC command that saves the active config, replacing the startup config file used when the switch initializes.
copy startup-config running-config	Enable mode EXEC command that merges the startup config file with the currently active config file in RAM.
show running-config	Lists the contents of the running config file.
write erase **erase startup-config**	These enable mode EXEC commands to erase the startup config file.
quit	EXEC command that disconnects the user from the CLI session.
show startup-config	Lists the contents of the startup config (initial config) file.
enable	Moves the user from user mode to enable (privileged) mode and prompts for a password if one is configured.
disable	Moves the user from enable mode to user mode.
configure terminal	Enable mode command that moves the user into configuration mode.

Chapter 8. Configuring Ethernet Switching

This chapter covers the following exam topics:

- **IP Routing Technologies**
  - Configure SVI interfaces
- **Network Device Security**
  - Configure and verify network device security features such as
    - Device password security
    - Enable secret vs enable
    - SSH
    - VTYs
    - Service password
    - Describe external authentication methods
  - Configure and verify Switch Port Security features such as
    - Sticky MAC
    - MAC address limitation
    - Static / dynamic
    - Violation modes
      - Err disable
      - Shutdown
      - Protect restrict
    - Shutdown unused ports
    - Err disable recovery
  - Assign unused ports to an unused VLAN

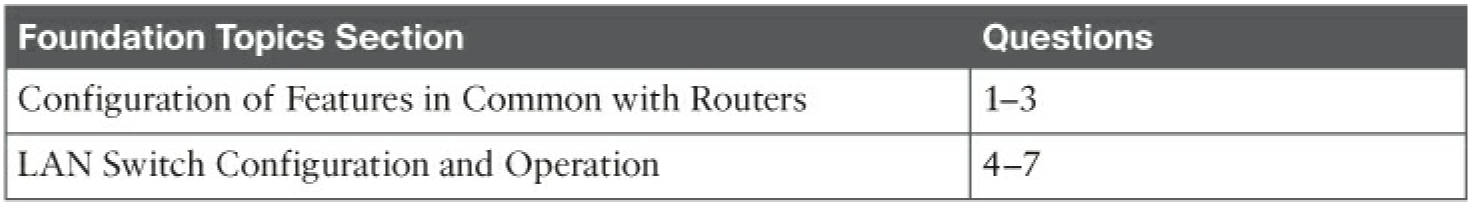
Cisco LAN switches perform their core function—forwarding Ethernet frames—without any configuration. You can buy a Cisco switch, plug in the right cables to connect various devices to the switch, plug in the power cable, and the switch works. However, in most networks, the network engineer wants to configure and use various switch features.

This chapter explains a large variety of switch features, broken into two halves of the chapter. The first half of the chapter explains many switch administrative features that happen to work the same way on routers and switches; this chapter keeps these common features together so that you can easily refer to them later when working with routers. The second half of the chapter shows how to configure some switch-specific features, many of which impact how a switch forwards frames.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 8-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Configuration of Features in Common with Routers	1–3
LAN Switch Configuration and Operation	4–7

1. Imagine that you have configured the **enable secret** command, followed by the **enable password** command, from the console. You log out of the switch and log back in at the console. Which command defines the password that you had to enter to access privileged mode?
   - **a. enable password**
   - **b. enable secret**
   - **c.** Neither
   - **d.** The **password** command, if it's configured
2. An engineer had formerly configured a Cisco 2960 switch to allow Telnet access so that the switch expected a password of **mypassword** from the Telnet user. The engineer then changed the configuration to support Secure Shell. Which of the following commands could have been part of the new configuration? (Choose two answers.)
   - **a.** A **username** *name* **password** *password* vty mode subcommand
   - **b.** A **username** *name* **password** *password* global configuration command

- **c.** A **login local** vty mode subcommand
- **d.** A **transport input ssh** global configuration command

3. The following command was copied and pasted into configuration mode when a user was telnetted into a Cisco switch:

```
banner login this is the login banner
```

Which of the following is true about what occurs the next time a user logs in from the console?

- **a.** No banner text is displayed.
- **b.** The banner text "his is" is displayed.
- **c.** The banner text "this is the login banner" is displayed.
- **d.** The banner text "Login banner configured, no text defined" is displayed.

4. Which of the following is required when configuring port security with sticky learning?

- **a.** Setting the maximum number of allowed MAC addresses on the interface with the **switchport port-security maximum** interface subcommand
- **b.** Enabling port security with the **switchport port-security** interface subcommand
- **c.** Defining the specific allowed MAC addresses using the **switchport port-security mac-address** interface subcommand
- **d.** All the other answers list required commands

5. An engineer's desktop PC connects to a switch at the main site. A router at the main site connects to each branch office through a serial link, with one small router and switch at each branch. Which of the following commands must be configured on the branch office switches, in the listed configuration mode, to allow the engineer to telnet to the branch office switches? (Choose three answers.)

- **a.** The **ip address** command in VLAN configuration mode
- **b.** The **ip address** command in global configuration mode
- **c.** The **ip default-gateway** command in VLAN configuration mode
- **d.** The **ip default-gateway** command in global configuration mode
- **e.** The **password** command in console line configuration mode
- **f.** The **password** command in vty line configuration mode

6. Which of the following describes a way to disable IEEE standard autonegotiation on a 10/100 port on a Cisco switch?

- **a.** Configure the **negotiate disable** interface subcommand
- **b.** Configure the **no negotiate** interface subcommand
- **c.** Configure the **speed 100** interface subcommand
- **d.** Configure the **duplex half** interface subcommand
- **e.** Configure the **duplex full** interface subcommand
- **f.** Configure the **speed 100** and **duplex full** interface subcommands

7. In which of the following modes of the CLI could you configure the duplex setting for interface Fast Ethernet 0/5?

- **a.** User mode
- **b.** Enable mode
- **c.** Global configuration mode
- **d.** VLAN mode
- **e.** Interface configuration mode

Answers to the "Do I Know This Already?" quiz:

1 B 2 B and C 3 B 4 B 5 A, D, and F 6 F 7 E

Foundation Topics

Configuration of Features in Common with Routers

This first of the two major sections of this chapter examines the configuration of several features that are configured the exact same way on both switches and routers. In particular, this section examines how to secure access to the CLI, plus various settings for the console. Note that this section will refer to only switches, and not routers, but the commands apply to both.

Securing the Switch CLI

The first step to securing a switch is to secure access to the CLI. Securing the CLI includes protecting access to enable mode, because from enable mode, an attacker could reload the switch or change the configuration. At the same time, protecting user mode is also important, because attackers can see the status of the switch, learn about the network, and find new ways to attack the network.

For example, consider a user who accesses a switch from the console. The default console configuration settings allow a console user to reach both user mode and enable mode without supplying a password. These defaults make some sense, because when you use the console, you are typically sitting near or next to the switch. If you can touch the switch, even if the console had all the available password protections, you could still perform the switch password recovery/reset procedure in five minutes anyway and get into the switch. So, by default, console access is open. However, most network engineers add login security to the console as well.

> **Note**
>
> To see the password recovery/reset procedures, go to Cisco.com and search for the phrase "password recovery." The first listed item probably will be a web page with password recovery details for most every product made by Cisco.

On the other hand, the default configuration settings do not allow a vty (Telnet or SSH) session into a switch, either to user mode or to enable mode. To allow these users to reach user mode, the switch first needs a working IP configuration, as well as login security on the vty lines. To allow access to enable mode, the switch must be configured with enable mode security as well.

This section examines many of the configuration details related to accessing user and enable mode on a switch or router. Switch IP configuration is covered later in this chapter in the section "Enabling IP for Remote Access." In particular, this section covers the following topics:

- Simple password security to user mode from (a) the console and (b) Telnet
- Secure Shell (SSH)
- Password encryption
- Enable mode passwords

Securing Access with Simple Passwords

Cisco switches can protect user mode with a simple password—with no username—for console and Telnet users. Console users must supply the *console password*, as configured in console line configuration mode. Telnet users must supply the *Telnet password*, also called the vty password, so called because the configuration sits in vty line configuration mode.

Cisco switches protect enable mode for any user with the *enable password*. The user, in user mode, types the **enable** EXEC command and is prompted for this enable password; if the user types the correct password, IOS moves the user to enable mode. Figure 8-1 shows the names of these passwords and the associated configuration modes.

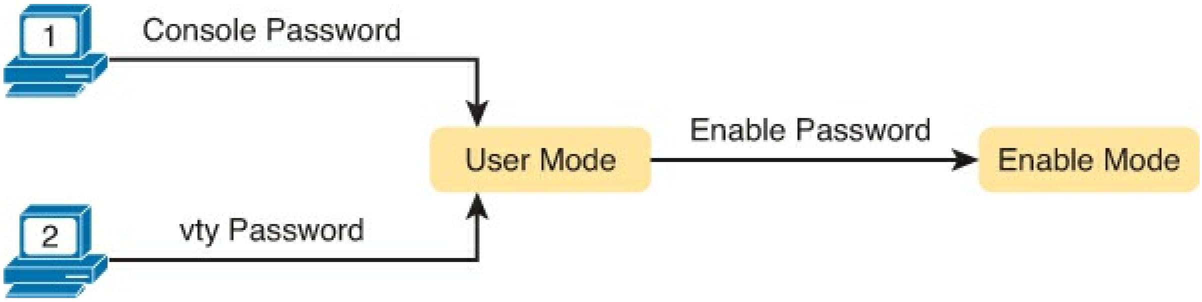


Figure 8-1. Simple Password Security Concepts

The configuration for these passwords does not require a lot of work. First, the console and vty password configuration uses the same two subcommands in console and vty line configuration modes, respectively. The **login** command tells IOS to use simple password security, and the **password** *password-value* command defines the password. IOS protects enable mode using the enable secret password, configured using the global command **enable secret** *password-value*.

> **Note**
>
> The later section "Hiding the Enable Password" explains two options for configuring the password required by the **enable** command, as configured with the **enable secret** and **enable password** commands, and describes why the **enable secret** command is preferred.

Example 8-1 shows a sample configuration process that sets the console password, the vty (Telnet) password, the enable secret password, and a host name for the switch. The example shows the entire process, including command prompts, that provides some reminders of the different configuration modes explained in Chapter 7, "Installing and Operating Cisco LAN Switches."

Key Topic

Example 8-1. Configuring Basic Passwords and a Host Name

```
Switch> enable
Switch# configure terminal
Switch(config)# enable secret cisco
Switch(config)# hostname Emma
Emma(config)# line console 0
Emma(config-line)# password faith
Emma(config-line)# login
Emma(config-line)# exit
Emma(config)# line vty 0 15
Emma(config-line)# password love
Emma(config-line)# login
Emma(config-line)# end
Emma#
```

Because you have probably not done many configurations yourself yet, the next few paragraphs walk you through Example 8-1 a few lines at a time, to use this example as an exercise in how the CLI works. First, focus on the first four lines, with the command prompts that begin with "Switch." By the publisher's conventions, this book lists all text output displayed by the switch in nonbold text and all text typed by the user in bold text. For example, the first line shows a command prompt supplied by the switch of "Switch>" (the default prompt, by the way), with the user typing **enable**. The ">" at the end of the prompt tells us that the user is in user mode.

Those first few lines show the user beginning in user mode, and then moving to enable mode (using the **enable** EXEC command). Then the user moves to global configuration mode (by using the **configure terminal** EXEC command). As soon as the user is in global configuration mode, he enters two global configuration commands (**enable secret** and **hostname**) that add configuration that applies to the entire switch.

The first line of output in Example 8-1 that begins with "Emma" shows the beginning of the configuration of the console password. First, the user needs to enter console line configuration mode using the **line console 0** command. (With only one console per switch, it is always numbered as console 0.) Next, the **password** command lists the simple text password (faith), and the **login** command tells the switch to ask for the simple text password as defined by the password command.

Continuing through the example, the next few lines repeat the same process, but for all 16 vty lines (vty lines 0 through 15). The 16 vty lines means that the switch can accept 16 concurrent Telnet connections into the switch. As for the password, the configuration uses a different vty line password of "love." Finally, the **end** command moves the user back to enable mode.

Moving on from the configuration, now focus on what the users will see because of the configuration in Example 8-1. A console user will now be prompted for a password (but no username), and he must type **hope**. Similarly, Telnet users will be prompted for a password, but no username, and they must type **love**. Both console and Telnet users must use the **enable** command, and use password "cisco," to reach enable mode. And SSH users cannot yet log in to this switch, because more configuration is needed to support SSH.

Example 8-2 shows the resulting configuration in the switch named Emma. The gray lines highlight the new configuration. Note that some lines have been omitted from the full output from a switch just to reduce the volume of unrelated lines on the page.

Example 8-2. Resulting Running Config File on Switch Emma

Click here to view code image

```
Emma# show running-config
!
Building configuration...

Current configuration : 1333 bytes
!
version 12.2
!
hostname Emma
!
enable secret 5 $1$YXRN$11zOe1Lb0Lv/nHyTquobd.
!
```

```
spanning-tree mode pvst
spanning-tree extend system-id
!
interface FastEthernet0/1
!
interface FastEthernet0/2
!
! Several lines have been omitted here - in particular, lines for FastEthernet
! interfaces 0/3 through 0/23.
!
interface FastEthernet0/24
!
interface GigabitEthernet0/1
!
interface GigabitEthernet0/2
!
interface Vlan1
no ip address
no ip route-cache
!
!
line con 0
password faith
login
!
line vty 0 4
password love
login
!
line vty 5 15
password love
login
```

Note

The output of the **show running-config** command, in the last six lines of Example 8-2, separates the first five vty lines (0 through 4) from the rest (5 through 15) for historical reasons.

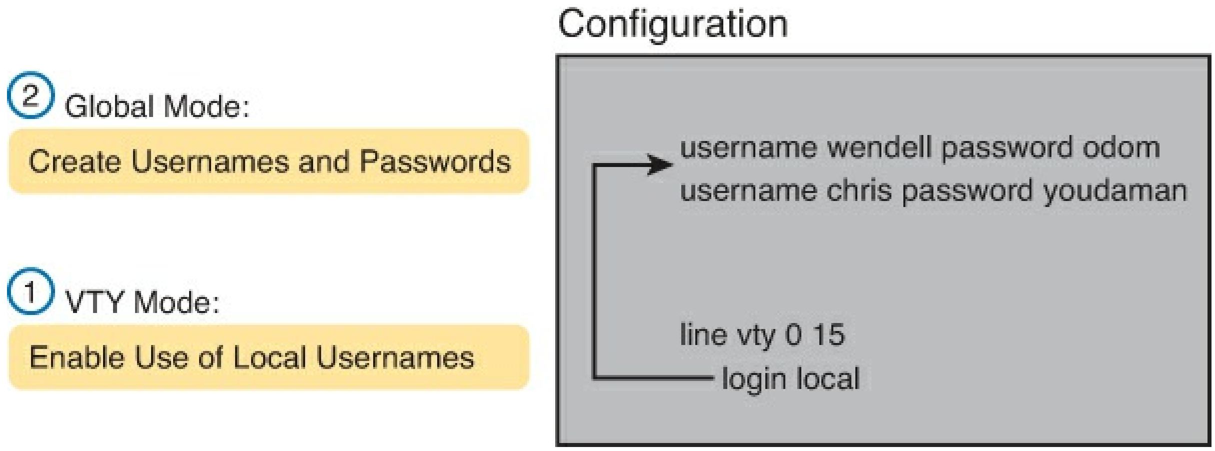
Securing Access with Local Usernames and Passwords

A login method that uses simple text passwords (without usernames) works, but it requires that everyone know the same passwords. For example, all must know the same vty password to get access to the switch using Telnet.

Cisco switches support other login authentication methods that use a username and password so that each user has unique login details that do not have to be shared. One method configures the username/password pairs locally on the switch, and the other relies on an external server called an authentication, authorization, and accounting (AAA) server. (The server could be the same server used for logins for other servers in the network.) This book covers the configuration using locally configured usernames/passwords.

The migration from using the password-only login method to using locally configured usernames and passwords requires only some small configuration changes. The switch needs one or more **username** *name* **password** *password* global configuration commands to define the usernames and passwords. Then the vty and/or console line needs to be told to make use of a locally configured username and password (per the **login local** line subcommand). For example, Figure 8-2 shows the concept and configuration to migrate to using local usernames for Telnet users.

Key Topic



```
username wendell password odom
username chris password youdaman

line vty 0 15
 login local
```

Figure 8-2. Configuring Switches to Use Local Username Login Authentication

When a Telnet user connects to the switch configured as shown in Figure 8-2, the user will be prompted first for a username and then for a password. The username/password pair must be from the list of local usernames, or the login is rejected.

Note

Figure 8-2 lists the configuration commands in the same order as seen in the IOS **show running-config** command.

Securing Access with External Authentication Servers

Using a local list of usernames and passwords on a switch or router works well in small networks. However, using locally configured username/password pairs means that every switch and router needs the configuration for all users who might need to log in to the devices. Then, when any changes need to happen, like an occasional change to the passwords, the configuration of all devices must be changed.

Cisco switches and routers support an alternative way to keep track of valid usernames and passwords by using an external AAA server. When using a AAA server for authentication, the switch (or router) simply sends a message to the AAA server asking whether the username and password are allowed, and the AAA server replies. Figure 8-3 shows an example, with the user first supplying his username/password, the switch asking the AAA server, and the server replying to the switch stating that the username/password is valid.

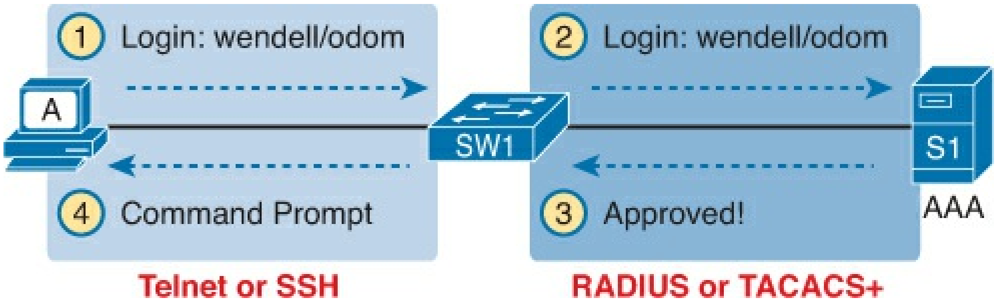


Figure 8-3. Basic Authentication Process with an External AAA Server

While the figure shows the general idea, note that the information flows with a couple of different protocols. On the left, the connection between the user and the switch or router uses Telnet or SSH. On the right, the switch and AAA server typically use either the RADIUS or TACACS+ protocol, both of which encrypt the passwords as they traverse the network.

Configuring Secure Shell (SSH)

To support SSH, Cisco switches require the base configuration used to support Telnet login with usernames, plus additional configuration. First, the switch already runs an SSH server by default, accepting incoming SSH connections from SSH clients. In addition, the switch needs a cryptography key, used to encrypt the data. The following list details the steps for a Cisco switch to support SSH using local usernames, with Step 3 listing the new commands specific to SSH support:

Key Topic

Step 1. Configure the vty lines to use usernames, with either locally configured usernames (using the **login local** command) or a AAA server.

Step 2. If using locally defined usernames, add one or more **username** global configuration commands to configure username/password pairs.

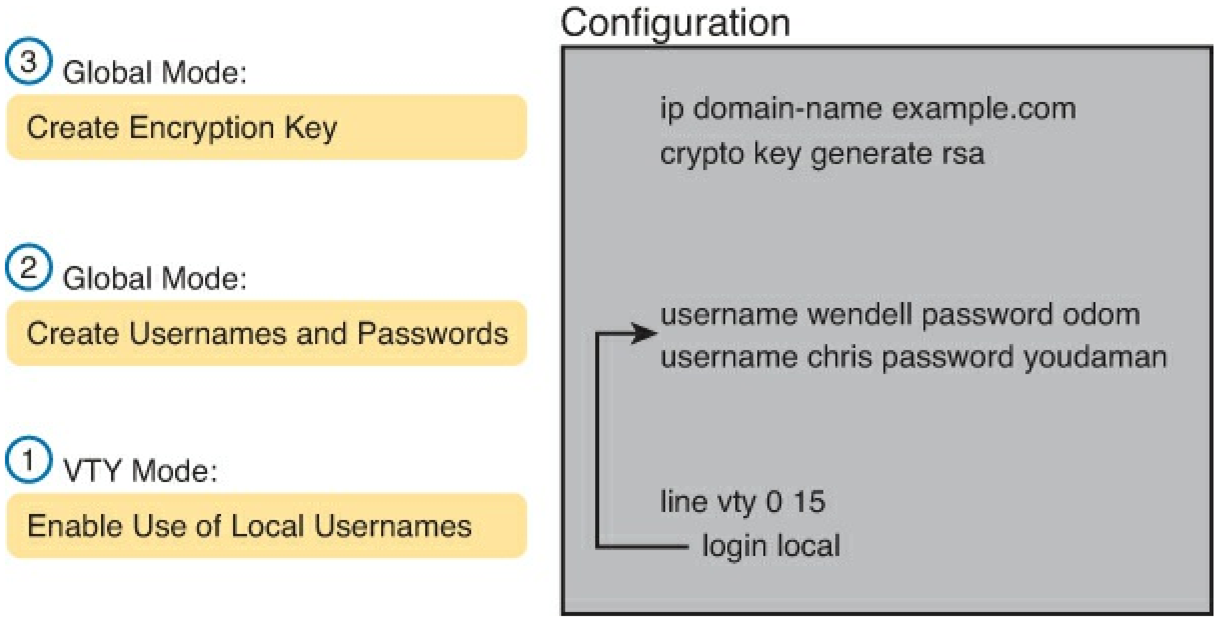
Step 3. Configure the switch to generate a matched public and private key pair to use for encryption, using two commands:

  A. As a prerequisite for the next command, configure a DNS domain name with the **ip domain-name** *name* global configuration command.

  B. Create the encryption keys using the **crypto key generate rsa** global configuration command.

Step 4. (Optional) Enable SSH Version 2 using the **ip ssh version 2** global command for enhanced security.

Figure 8-4 shows the three steps, with examples of the required configuration commands. Note that this figure adds to the configuration shown in Figure 8-2, with only two more commands added to support SSH.



```
ip domain-name example.com
crypto key generate rsa

username wendell password odom
username chris password youdaman

line vty 0 15
 login local
```

Figure 8-4. Configuring a Switch to Support Inbound SSH Login

> **Note**
>
> If you wonder why the figure shows the order from bottom to top, it is because the output of the **show running-config** command will list these configuration commands in the order shown in the figure.

Seeing the configuration happen in configuration mode, step by step, can be particularly helpful with SSH. Note in particular that the **crypto key** command actually prompts the user for more information and generates some messages while the key is being generated. Example 8-3 shows the commands in Figure 8-4 being configured, with the encryption key as the final step.

Example 8-3. SSH Configuration Process

Click here to view code image

```
Emma# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
Emma(config)# line vty 0 15
! Step 1's key command happens next
Emma(config-line)# login local
Emma(config-line)# exit
!
! Step 2's command happens next
Emma(config)# username wendell password odom
Emma(config)# username chris password youdaman
!
! Step 3's two commands happen next
Emma(config)# ip domain-name example.com
Emma(config)# crypto key generate rsa
The name for the keys will be: Emma.example.com
```

```
Choose the size of the key modulus in the range of 360 to 2048 for your
General Purpose Keys. Choosing a key modulus greater than 512 may take
a few minutes.

How many bits in the modulus [512]: 1024
% Generating 1024 bit RSA keys, keys will be non-exportable...
[OK] (elapsed time was 4 seconds)

Emma(config)# ip ssh version 2
Emma(config)# ^Z
Emma#
```

Two key commands give some information about the status of SSH on the switch. First, the **show ip ssh** command lists status information about the SSH server itself. The **show ssh** command then lists information about each SSH client currently connected into the switch. Example 8-4 shows samples of each, with user Wendell currently connected to the switch.

Example 8-4. Displaying SSH Status

Click here to view code image

```
Emma# show ip ssh
SSH Enabled - version 2.0
Authentication timeout: 120 secs; Authentication retries: 3
Minimum expected Diffie Hellman key size : 1024 bits
IOS Keys in SECSH format(ssh-rsa, base64 encoded):
ssh-rsa AAAAB3NzaC1yc2EAAAADAQABAAAAgQC+/mp2iaeaGwjqkIgLNH+lN/04LTc2u6qHVHHv3hoq
/DDBd9vABNnJGsq8z0Hm9HcrSudC20N/cCuEb4x5+T9rvNkUeAqwEEoJALpdiWVOpBliomhPysvJi+m4
wI16AH31KI+GFCZv1AIjZSYHQEbvdCEqsYezAeKnPhvzTrUqaQ==

Emma# show ssh
Connection Version Mode Encryption Hmac State Username
0 2.0 IN aes128-cbc hmac-sha1 Session started wendell
0 2.0 OUT aes128-cbc hmac-sha1 Session started wendell
%No SSHv1 server connections running.
```

Note that this example does use SSH Version 2 rather than Version 1. SSH v2 improves the underlying security algorithms over SSH v1 and adds some other small advantages, like banner support.

Finally, the switch supports both Telnet and SSH on the vty lines, but you can disable either or both for even tighter security. For example, your company might require that you avoid Telnet because of the security risk, so you need to disable Telnet support on the switch. Switches can control their support of Telnet and/or SSH on the vty lines using the **transport input {all | none | telnet | ssh}** vty subcommand, with the following options:

transport input all or **transport input telnet ssh:** Support both

transport input none: Support neither

transport input telnet: Support only Telnet

transport input ssh: Support only SSH

Encrypting and Hiding Passwords

Several of the configuration commands discussed so far in this chapter list passwords in clear text in the running config file (at least by default). In fact, of the commands discussed in this chapter so far, only the **enable secret** command automatically hides the password value. The other commands—the console and vty lines with the **password** command, plus the password in the **username password** command—store the password in clear text by default.

The next few sections discuss several options for hiding password values. Some tools use encryption, and some use a one-way hash algorithm. Regardless of the detail, the result is that the passwords cannot be seen by anyone who happens to see the output of the **show running-config** command.

Encrypting Passwords with the service password Command

To prevent password vulnerability in a printed version of the configuration file, or in a backup copy of the configuration file stored on a server, you can encrypt some passwords using the **service password-encryption** global configuration command. This command affects how IOS stores passwords for the **password** command, in both console and vty modes, and the **username password** global command. The rules for the **service password-config** command are as follows:

- At the moment that the **service password-encryption** command is configured, IOS immediately encrypts all existing **password** commands (in console and vty modes) and **username password** (global command) passwords.
- While the **service password-encryption** command remains in the configuration, IOS encrypts these same passwords if

their values are changed.

- At the moment the **no service password-encryption** command is used, disabling password encryption, IOS does nothing to the existing passwords, leaving them all as encrypted.
- From that point forward, while the **service password-encryption** command is no longer in the configuration, IOS stores any changed password values for these commands as clear text.

Example 8-5 shows an example of these details.

Example 8-5. Encryption and the service password-encryption **Command**

Click here to view code image

```
Switch3# show running-config | begin line vty
line vty 0 4
password cisco
login
line vty 5 15
password cisco
login

Switch3# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
Switch3(config)# service password-encryption
Switch3(config)# ^Z

Switch3# show running-config | begin line vty
line vty 0 4
password 7 070C285F4D06
login
line vty 5 15
password 7 070C285F4D06
login
end
Switch3# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
Switch3(config)# no service password-encryption
Switch3(config)# ^Z
Switch3# show running-config | section vty
line vty 0 4
password 7 070C285F4D06
login
line vty 5 15
password 7 070C285F4D06
login
end

Switch3# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
Switch3(config)# line vty 0 4
Switch3(config-line)# password cisco
Switch3(config-line)# ^Z

Switch3# show running-config | begin line vty
line vty 0 4
password cisco
login
line vty 5 15
password 7 070C285F4D06
login
end
```

Note

The encryption type used by the **service password-encryption** command, as noted with the “7” in the **password** commands, is weak. You can search the Internet and find sites with tools to decrypt these passwords. In fact, you can take the encrypted password from this example, plug it into one of these sites, and it decrypts to “cisco.” So, the **service password-encryption** command will slow down the curious, but it will not stop a knowledgeable attacker.

Example 8-5 also shows several examples of the pipe function (|), available at the end of CLI **show** commands. The | at the end of a **show** command sends (pipes) the output of the command to another function, like the **begin** and **section** functions shown in Example 8-5. The **begin** function, as shown in the **show running-config** | **begin line vty** command in the example, takes the output from the command and starts listing the text beginning when the first occurrence of the listed text ("vty" in this case) shows up. The | **section vty** parameters, also seen in example 8-5, display only the section of output about the vty lines.

Hiding the Enable Password

Switches can protect enable mode by requiring that the user supply an enable password after using the **enable** EXEC command. However, the configuration can be based on two different commands: the older **enable password** *password* global command and the newer (and preferred) **enable secret** *password* global command.

IOS allows you to configure neither, one or the other, or even both of these commands. Then the switch chooses what password to require of a user based on the following rules:

Key Topic

- **Both commands configured:** Use the **enable secret** *password* command
- **Only one command configured:** Use the password in that one command
- **Neither command configured (default):** Console users are allowed into enable mode without a password prompt, while others are rejected.

The newer **enable secret** command provides much better security compared to the older **enable password** command. The older **enable password** command stores the password as clear text, and the only option to encrypt it is the weak **service password-encryption** command. The newer **enable secret** command automatically encodes the password, using a different process than the **service password-encryption** command. This newer command applies a mathematical function to the password, called a Message Digest 5 (MD5) hash, storing the results of the formula in the **enable secret** command in the configuration file.

Example 8-6 shows the creation of the **enable secret** command, and describes how it hides the password text. The example first lists the **enable secret fred** command, as typed by the user. Later, the **show running-configuration** command shows that IOS changed the **enable secret** command, now listing encryption type 5 (meaning it is an MD5 hash). The gobbledygook long text string is the MD5 hash, preventing others from reading the password.

Example 8-6. Encryption and the enable secret **Command**

Click here to view code image

```
Switch3(config)# enable secret ?
0 Specifies an UNENCRYPTED password will follow
5 Specifies an ENCRYPTED secret will follow
LINE The UNENCRYPTED (cleartext) 'enable' secret
level Set exec level password

Switch3(config)# enable secret fred
Switch3(config)# ^Z
Switch3# show running-config | include enable secret

enable secret 5 $1$ZGMA$e8cmvkz4UjiJhVp7.maLE1

Switch3# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
Switch3(config)# no enable secret
Switch3(config)# ^Z
```

The end of the example also shows an important point about deleting the enable secret password: After you are in enable mode, you can delete the enable secret password using the **no enable secret** command, without even having to enter the password value. You can also overwrite the old password by just repeating the command.

> **Note**
>
> Example 8-6 shows another shortcut with working through long **show** command output, using the pipe to the **include** command. The **show running-config | include enable secret** command lists the output from **show running-config**, but only lines that include the case-sensitive text "enable secret."

Finally, note that Cisco has added another hash algorithm to the **enable secret** command for routers: SHA-256. This algorithm is stronger than MD5, with IOS listing this algorithm as encryption type 4. Over time, Cisco will likely add SHA-256 support to switches as well. Regardless, the effect of using SHA-256 or MD5 is the same: The user configures a command like **enable secret fred**, typing the cleartext password, and IOS stores the hash value as either MD5 (older IOS versions) or SHA-256 (newer IOS versions).

Hiding the Passwords for Local Usernames

Cisco added the **enable secret** command, and its better password protection, back in the 1990s. More recently, Cisco has added the **username** *user* **secret** *password* global command as an alternative to the **username** *user* **password** *password* command. Note that this command uses an SHA-256 (type 4) hash.

Today, the **username secret** command is preferred over the **username password** command, much like the **enable secret** command is preferred over the **enable password** command. However, note that a username can be configured with either the **username secret** command or the **username password** command, but not both.

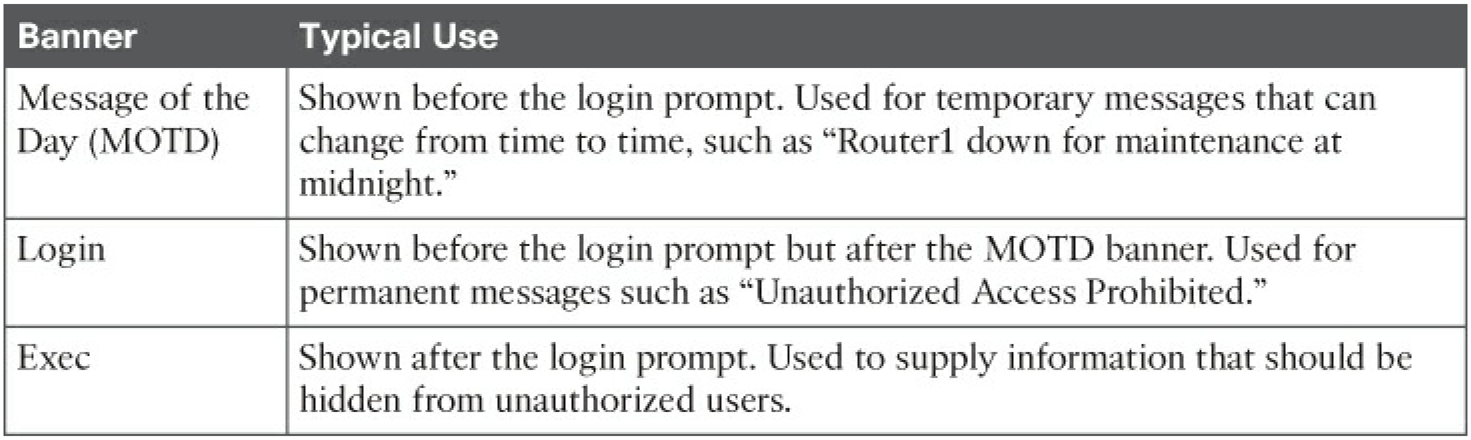
Console and vty Settings

This section covers a few small configuration settings that affect the behavior of the CLI connection from the console and/or vty (Telnet and SSH).

Banners

Cisco switches can display a variety of banners depending on what a router or switch administrator is doing. A banner is simply some text that appears on the screen for the user. You can configure a router or switch to display multiple banners, some before login and some after. Table 8-2 lists the three most popular banners and their typical use.

Table 8-2. Banners and Their Use



Banner	Typical Use
Message of the Day (MOTD)	Shown before the login prompt. Used for temporary messages that can change from time to time, such as "Router1 down for maintenance at midnight."
Login	Shown before the login prompt but after the MOTD banner. Used for permanent messages such as "Unauthorized Access Prohibited."
Exec	Shown after the login prompt. Used to supply information that should be hidden from unauthorized users.

The **banner** global configuration command can be used to configure all three types of these banners. In each case, the type of banner is listed as the first parameter, with MOTD being the default option. The first nonblank character after the banner type is called a beginning delimiter character. The banner text can span several lines, with the CLI user pressing Enter at the end of each line. The CLI knows that the banner has been configured as soon as the user enters the same delimiter character again.

Example 8-7 shows the configuration process for all three types of banners from Table 8-2, followed by a sample user login session that shows the banners in use. The first banner in the example, the MOTD banner, omits the banner type in the **banner** command as a reminder that **motd** is the default banner type. The first two **banner** commands use a # as the delimiter character. The third **banner** command uses a Z as the delimiter, just to show that any character can be used. Also, the last **banner** command shows multiple lines of banner text.

Example 8-7. Banner Configuration

Click here to view code image

```
! Below, the three banners are created in configuration mode. Note that any
! delimiter can be used, as long as the character is not part of the message
! text.

SW1(config)# banner #
Enter TEXT message. End with the character '#'.
(MOTD) Switch down for maintenance at 11PM Today #
SW1(config)# banner login #
Enter TEXT message. End with the character '#'.
(Login) Unauthorized Access Prohibited!!!!
#
SW1(config)# banner exec Z
Enter TEXT message. End with the character 'Z'.
```

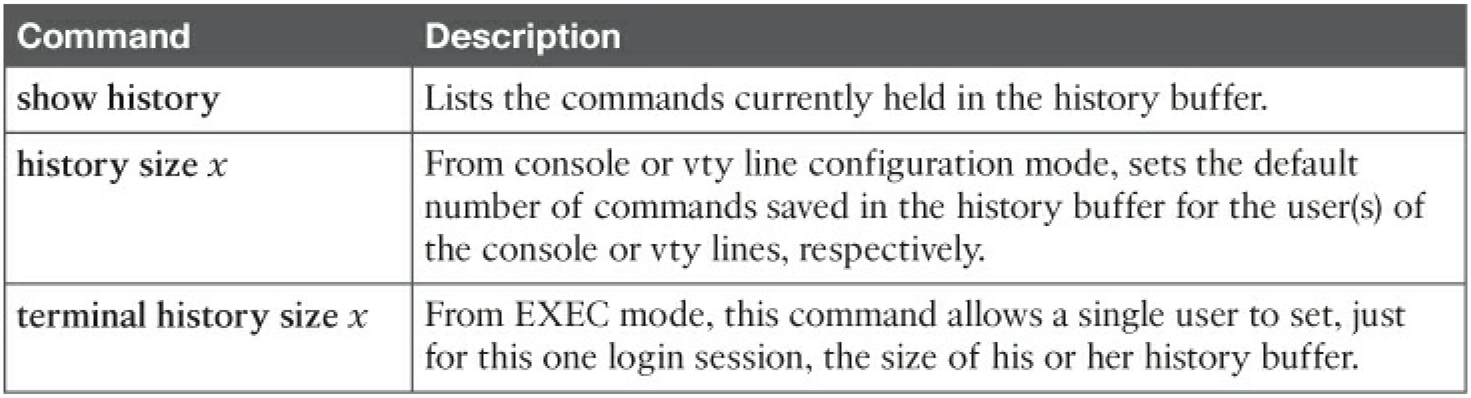
```
(Exec) Company picnic at the park on Saturday
Don't tell outsiders!
Z
SW1(config)# end

! Below, the user of this router quits the console connection, and logs back in,
! seeing the motd and login banners, then the password prompt, and then the
! exec banner.
SW1#quit

SW1 con0 is now available

Press RETURN to get started.

(MOTD) Switch down for maintenance at 11PM Today
(Login) Unauthorized Access Prohibited!!!!

User Access Verification

Username: fred
Password:
(Exec) Company picnic at the park on Saturday
don't tell outsiders!
SW1>
```

History Buffer Commands

When you enter commands from the CLI, the last several commands are saved in the history buffer. As mentioned in Chapter 7, you can use the up-arrow key, or press Ctrl+P, to move back in the history buffer stack to retrieve a command you entered a few commands ago. This feature makes it very easy and fast to use a set of commands repeatedly. Table 8-3 lists some of the key commands related to the history buffer.

Key Topic

Table 8-3. Commands Related to the History Buffer



Command	Description
show history	Lists the commands currently held in the history buffer.
history size *x*	From console or vty line configuration mode, sets the default number of commands saved in the history buffer for the user(s) of the console or vty lines, respectively.
terminal history size *x*	From EXEC mode, this command allows a single user to set, just for this one login session, the size of his or her history buffer.

The logging synchronous and exec-timeout Commands

The next short section looks at a couple of ways to make using the console a little more user friendly, by asking the switch to not interrupt with log messages, and to control how long you can be connected to the console before getting forced out.

The console automatically receives copies of all unsolicited syslog messages on a switch. The idea is that if the switch needs to tell the network administrator some important and possibly urgent information, the administrator might be at the console and might notice the message.

The display of these messages at the console can be disabled and enabled with the **no logging console** and **logging console** global commands. For example, when working from the console, if you want to temporarily not be bothered by log messages, you can disable the display of these messages with the **no logging console** global configuration command, and then when finished, enable them again.

Unfortunately, IOS (by default) displays these syslog messages on the console’s screen at any time—including right in the middle of a command you are entering, or in the middle of the output of a **show** command. Having a bunch of text show up unexpectedly can be a bit annoying.

IOS supplies a solution to this problem by telling the switch to display syslog messages only at more convenient times, such as at the end of output from a **show** command. To do so, just configure the **logging synchronous** console line subcommand.

Another way to improve the user experience at the console is to control timeouts from the console. By default, the switch automatically disconnects console and vty (Telnet and SSH) users after 5 minutes of inactivity. The **exec-timeout** *minutes seconds* line subcommand lets you set the length of that inactivity timer, with the special value of 0 minutes and 0 seconds meaning "never time out."

Example 8-8 shows the syntax for these two commands, both on the console line. Note that both can be applied to the vty lines as well, for the same reasons.

Example 8-8. Defining Console Inactivity Timeouts and When to Display Log Messages

```
line console 0
login
password cisco
exec-timeout 0 0
logging synchronous
```

> **Note**
>
> This concludes the first half of this chapter. If you have not yet tried any commands on a router or switch, now would be a good time to pause from your reading and try some. If you have real gear, or the Pearson Simulator, do some labs about navigating the CLI, setting passwords, and other basic administration. If not, watch the videos from the DVD on CLI navigation and route configuration. Also, try a few labs from the ICND1 Simulator Lite on the DVD. Even if you do a lab on something you have not seen yet, you can get a little better idea about how to move around with the command-line interface.

LAN Switch Configuration and Operation

Cisco switches work very well when received from the factory, without any configuration added. Cisco switches leave the factory with default settings, with all interfaces enabled (a default configuration of **no shutdown**) and with autonegotiation enabled for ports that can use it (a default configuration of **duplex auto** and **speed auto**). All interfaces default to be part of VLAN 1 (**switchport access vlan 1**). All you have to do with a new Cisco switch is make all the physical connections—Ethernet cables and power cord—and the switch starts working.

In most enterprise networks, you will want the switch to operate with some different settings as compared with the factory defaults. The second half of this chapter discusses some of those settings, with Chapter 9 ("Implementing Ethernet Virtual LANs") discussing more. (Also note that the details in this section differ from the configuration on a router.) In particular, this section covers the following:

- IP for remote access
- Interface configuration (including speed and duplex)
- Port security
- Securing unused switch interfaces

Enabling IP for Remote Access

To allow Telnet or SSH access to the switch, and to allow other IP-based management protocols (for example, Simple Network Management Protocol) to function as intended, the switch needs an IP address. The IP address has nothing to do with how switches forward Ethernet frames; it simply exists to support overhead management traffic.

A switch's IP configuration works like a PC with a single Ethernet interface. For perspective, a PC has a CPU, with the operating system running on the CPU. It has an Ethernet network interface card (NIC). The OS configuration includes an IP address associated with the NIC, either configured or learned dynamically with DHCP. To support IP, the switch has the equivalent settings.

A switch uses concepts similar to a host, except that the switch can use a virtual NIC. Like a PC, a switch has a real CPU, running an OS (called IOS). The switch then uses a NIC-like concept called a *switched virtual interface (SVI)*, or more commonly, a *VLAN interface*, that acts like the switch's own NIC for connecting into a LAN to send IP packets. Like a host, the switch configuration assigns IP settings, like an IP address, to this VLAN interface, as seen in Figure 8-5.

Key Topic

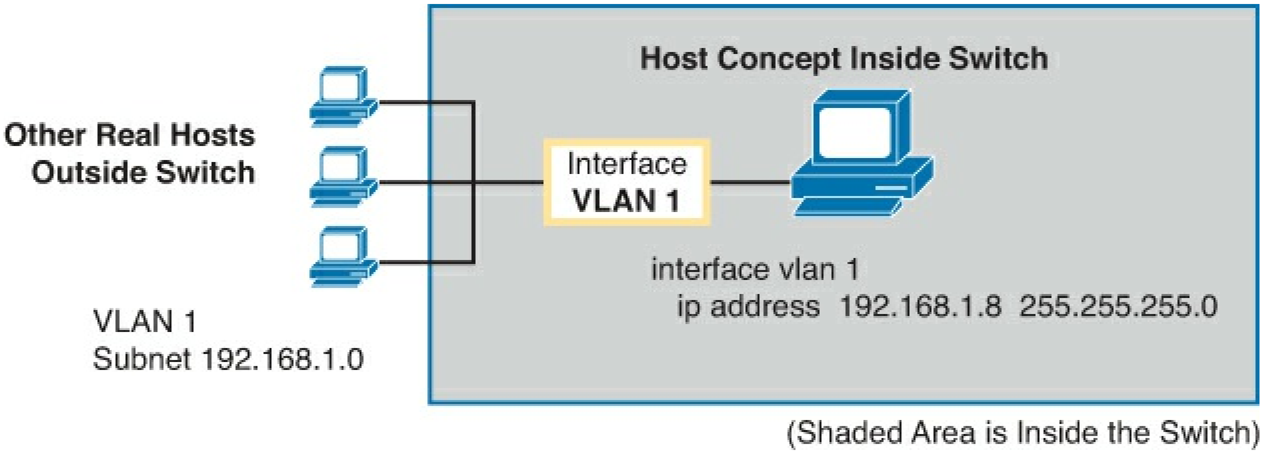

Host Concept Inside Switch
Other Real Hosts Outside Switch
Interface VLAN 1
interface vlan 1
ip address 192.168.1.8 255.255.255.0
VLAN 1
Subnet 192.168.1.0
(Shaded Area is Inside the Switch)

Figure 8-5. Switch Virtual Interface (SVI) Concept Inside a Switch

A typical Layer 2 Cisco LAN switch can use only one VLAN interface at a time, but the network engineer can choose which VLAN interface, putting the switch's management traffic into a particular VLAN. For example, Figure 8-6 shows a switch with some physical ports in two different VLANs (1 and 2). The network engineer needs to choose whether the switch IP address, used to access and manage the switch, should have an IP address in subnet 192.168.1.0 (in VLAN 1), or in subnet 192.168.2.0 (in VLAN 2).

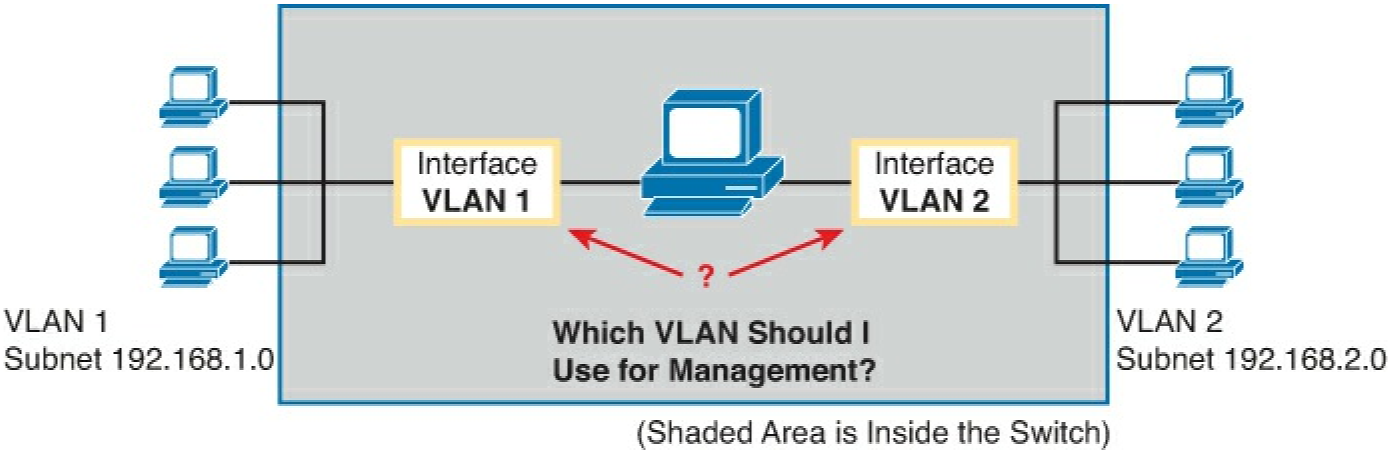

Interface VLAN 1
Interface VLAN 2
?
Which VLAN Should I Use for Management?
VLAN 1
Subnet 192.168.1.0
VLAN 2
Subnet 192.168.2.0
(Shaded Area is Inside the Switch)

Figure 8-6. Choosing One VLAN on Which to Configure a Switch IP Address

Note

Some Cisco switches, called *Layer 2 switches*, forward Ethernet frames as discussed in depth in Chapter 6, "Building Ethernet LANs with Switches." Other Cisco switches, called *multilayer switches* or *Layer 3 switches*, can also route IP packets using the Layer 3 logic normally used by routers. Layer 3 switches configure IP addresses on more than one VLAN interface at a time. This chapter assumes all switches are Layer 2 switches. Chapter 9 further defines the differences between these types of LAN switches.

Configuring IPv4 on a Switch

A switch configures its IPv4 address and mask on this special NIC-like *VLAN interface*. The following steps list the commands used to configure IPv4 on a switch, assuming that the IP address is configured to be in VLAN 1, with Example 8-9 that follows showing an example configuration.

Key Topic

Step 1. Enter VLAN 1 configuration mode using the **interface vlan 1** global configuration command.

Step 2. Assign an IP address and mask using the **ip address** *ip-address mask* interface subcommand.

Step 3. If not already enabled, enable the VLAN 1 interface using the **no shutdown** interface subcommand.

Step 4. Add the **ip default-gateway** *ip-address* global command to configure the default gateway.

Step 5. (Optional) Add the **ip name-server** *ip-address1 ip-address2 . . .* global command to configure the switch to use DNS to resolve names into their matching IP address.

Example 8-9. Switch Static IP Address Configuration

Click here to view code image

```
Emma# configure terminal
Emma(config)# interface vlan 1
Emma(config-if)# ip address 192.168.1.200 255.255.255.0
Emma(config-if)# no shutdown
00:25:07: %LINK-3-UPDOWN: Interface Vlan1, changed state to up
00:25:08: %LINEPROTO-5-UPDOWN: Line protocol on Interface Vlan1, changed
state to up
Emma(config-if)# exit
Emma(config)# ip default-gateway 192.168.1.1
```

On a side note, this example shows a particularly important and common command: the **[no] shutdown** command. To administratively enable an interface on a switch, use the **no shutdown** interface subcommand; to disable an interface, use the **shutdown** interface subcommand. The messages shown in Example 8-9, immediately following the **no shutdown** command, are syslog messages generated by the switch stating that the switch did indeed enable the interface.

The switch can also use DHCP to dynamically learn its IPv4 settings. Basically, all you have to do is tell the switch to use DHCP on the interface, and enable the interface. Assuming that DHCP works in this network, the switch will learn all its settings. The following list details the steps, again assuming the use of interface VLAN 1, with Example 8-10 that follows showing an example.

Key Topic

Step 1. Enter VLAN 1 configuration mode using the **interface vlan 1** global configuration command, and enable the interface using the **no shutdown** command as necessary.

Step 2. Assign an IP address and mask using the **ip address dhcp** interface subcommand.

Example 8-10. Switch Dynamic IP Address Configuration with DHCP

Click here to view code image

```
Emma# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
Emma(config)# interface vlan 1
Emma(config-if)# ip address dhcp
Emma(config-if)# no shutdown
Emma(config-if)# ^Z
Emma#
00:38:20: %LINK-3-UPDOWN: Interface Vlan1, changed state to up
00:38:21: %LINEPROTO-5-UPDOWN: Line protocol on Interface Vlan1, changed state to up
```

Verifying IPv4 on a Switch

The switch IPv4 configuration can be checked in several places. First, you can always look at the current configuration using the **show running-config** command. Second, you can look at the IP address and mask information using the **show interface vlan** *x* command, which shows detailed status information about the VLAN interface in VLAN *x*. Finally, if using DHCP, use the **show dhcp lease** command to see the (temporarily) leased IP address and other parameters. (Note that the switch does not store the DHCP-learned IP configuration in the running-config file.) Example 8-11 shows sample output from these commands to match the configuration in Example 8-10.

Example 8-11. Verifying DHCP-learned Information on a Switch

Click here to view code image

```
Emma# show dhcp lease
Temp IP addr: 192.168.1.101 for peer on Interface: Vlan1
Temp sub net mask: 255.255.255.0
DHCP Lease server: 192.168.1.1, state: 3 Bound
DHCP transaction id: 1966
Lease: 86400 secs, Renewal: 43200 secs, Rebind: 75600 secs
Temp default-gateway addr: 192.168.1.1
Next timer fires after: 11:59:45
Retry count: 0 Client-ID: cisco-0019.e86a.6fc0-Vl1
Hostname: Emma
Emma# show interfaces vlan 1
Vlan1 is up, line protocol is up
```

```
Hardware is EtherSVI, address is 0019.e86a.6fc0 (bia 0019.e86a.6fc0)
Internet address is 192.168.1.101/24
MTU 1500 bytes, BW 1000000 Kbit, DLY 10 usec,
reliability 255/255, txload 1/255, rxload 1/255
! lines omitted for brevity
Emma# show ip default-gateway
192.168.1.1
```

The output of the **show interfaces vlan 1** command lists two very important details related to switch IP addressing. First, this **show** command lists the interface status of the VLAN 1 interface—in this case, “up and up.” If the VLAN 1 interface is not up, the switch cannot use its IP address to send and receive traffic. Notably, if you forget to issue the **no shutdown** command, the VLAN 1 interface remains in its default shutdown state and is listed as “administratively down” in the **show** command output.

Second, note that the output lists the interface’s IP address on the third line. If you statically configure the IP address, as in Example 8-9, the IP address will always be listed. However, if you use DHCP, and DHCP fails, the **show interfaces vlan** *x* command will not list an IP address here. When DHCP works, you can see the IP address with this command, but it does not remind you whether the address is either statically configured or DHCP leased.

Configuring Switch Interfaces

IOS uses the term *interface* to refer to physical ports used to forward data to and from other devices. Each interface can be configured with several settings, each of which might differ from interface to interface.

IOS uses interface subcommands to configure these settings. For example, interfaces can be configured to use the **duplex** and **speed** interface subcommands to configure those settings statically, or an interface can use autonegotiation (the default). Example 8-12 shows how to configure duplex and speed, as well as the **description** command, which is simply a text description that can be configured by the administrator.

Example 8-12. Interface Configuration Basics

Click here to view code image

```
Emma# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
Emma(config)# interface FastEthernet 0/1
Emma(config-if)# duplex full
Emma(config-if)# speed 100
Emma(config-if)# description Server1 connects here
Emma(config-if)# exit
Emma(config)# interface range FastEthernet 0/11 - 20
Emma(config-if-range)# description end-users connect_here
Emma(config-if-range)# ^Z
Emma#
Emma# show interfaces status
Port Name Status Vlan Duplex Speed Type
Fa0/1 Server1 connects h notconnect 1 full 100 10/100BaseTX
Fa0/2 notconnect 1 auto auto 10/100BaseTX
Fa0/3 notconnect 1 auto auto 10/100BaseTX
Fa0/4 connected 1 a-full a-100 10/100BaseTX
Fa0/5 notconnect 1 auto auto 10/100BaseTX
Fa0/6 connected 1 a-full a-100 10/100BaseTX
Fa0/7 notconnect 1 auto auto 10/100BaseTX
Fa0/8 notconnect 1 auto auto 10/100BaseTX
Fa0/9 notconnect 1 auto auto 10/100BaseTX
Fa0/10 notconnect 1 auto auto 10/100BaseTX
Fa0/11 end-users connect notconnect 1 auto auto 10/100BaseTX
Fa0/12 end-users connect notconnect 1 auto auto 10/100BaseTX
Fa0/13 end-users connect notconnect 1 auto auto 10/100BaseTX
Fa0/14 end-users connect notconnect 1 auto auto 10/100BaseTX
Fa0/15 end-users connect notconnect 1 auto auto 10/100BaseTX
Fa0/16 end-users connect notconnect 1 auto auto 10/100BaseTX
Fa0/17 end-users connect notconnect 1 auto auto 10/100BaseTX
Fa0/18 end-users connect notconnect 1 auto auto 10/100BaseTX
Fa0/19 end-users connect notconnect 1 auto auto 10/100BaseTX
Fa0/20 end-users connect notconnect 1 auto auto 10/100BaseTX
Fa0/21 notconnect 1 auto auto 10/100BaseTX
Fa0/22 notconnect 1 auto auto 10/100BaseTX
Fa0/23 notconnect 1 auto auto 10/100BaseTX
Fa0/24 notconnect 1 auto auto 10/100BaseTX
```

```
    Gi0/1 notconnect 1 auto auto 10/100/1000BaseTX
    Gi0/2 notconnect 1 auto auto 10/100/1000BaseTX
```

You can see some of the details of interface configuration with both the **show running-config** command (not shown in the example) and the handy **show interfaces status** command. This command lists a single line for each interface, the first part of the interface description, and the speed and duplex settings. Several of the early entries in the output purposefully show some differences, as follows:

- **FastEthernet 0/1 (Fa0/1):** This output lists the configured speed of 100 and duplex full; however, it lists a status of notconnect. The notconnect status means that the physical link is not currently working, including reasons like no cable being connected, the other device being powered off, or the other device putting the port in a shutdown state. In this case, no cable had been installed when the output was gathered.
- **FastEthernet 0/2 (Fa0/2):** This port also has no cable installed yet, but it uses all default configuration. So, the highlighted output shows this interface with the default setting of auto (meaning autonegotiate).
- **FastEthernet 0/4 (Fa0/4):** Like Fa0/2, this port has all default configuration, but was cabled to another device that is up, causing the status to be listed as "connect." This device also completed the autonegotiation process, so the output lists the resulting speed and duplex (**a-full** and **a-100**), in which the **a-** refers to the fact that these values were autonegotiated.

Also, note that for the sake of efficiency, you can configure a command on a range of interfaces at the same time using the **interface range** command. In the example, the **interface range FastEthernet 0/11 - 20** command tells IOS that the next subcommand(s) apply to interfaces Fa0/11 through Fa0/20.

> **Note**
>
> Configuring both the speed and duplex on a Cisco switch interface disables autonegotiation.

Port Security

If the network engineer knows what devices should be cabled and connected to particular interfaces on a switch, the engineer can use *port security* to restrict that interface so that only the expected devices can use it. This reduces exposure to attacks in which the attacker connects a laptop to some unused switch port. When that inappropriate device attempts to send frames to the switch interface, the switch can take different actions, ranging from simply issuing informational messages to effectively shutting down the interface.

Port security identifies devices based on the source MAC address of Ethernet frames the devices send. For example, in Figure 8-7, PC1 sends a frame, with PC1's MAC address as the source address. SW1's F0/1 interface can be configured with port security, and if so, SW1 would think about PC1's MAC address and whether PC1 was allowed to send frames into port F0/1.

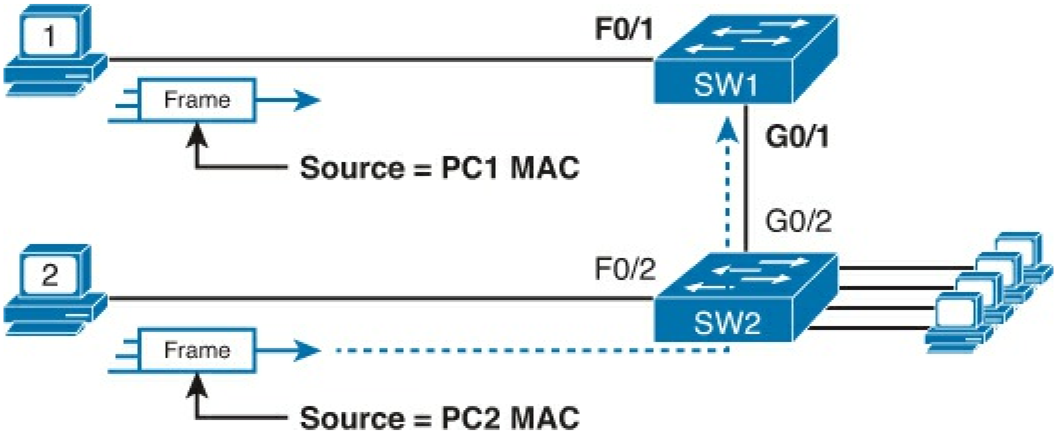


Figure 8-7. Source MAC Addresses in Frames as They Enter a Switch

Port security also has no restrictions on whether the frame came from a local device or it was forwarded through other switches. For example, switch SW1 could use port security on its G0/1 interface, checking the source MAC address of the frame from PC2, when forwarded up to SW1 from SW2.

Port security has several flexible options, but all operate with the same core concepts. First, switches enable port security per port, with different settings available per port. Each port has a maximum number of allowed MAC addresses, meaning that for all frames entering that port, only that number of *different* source MAC addresses can be used in different incoming frames before port security thinks a violation has occurred. When a frame with a new source MAC address arrives, pushing the number of MAC addresses past the allowed maximum, a port security violation occurs. At that point, the switch takes action—by default, discarding all future incoming traffic on that port.

The following list summarizes these ideas common to all variations of port security:

Key Topic

- Define a maximum number of source MAC addresses allowed for all frames coming in the interface.
- Watch all incoming frames, and keep a list of all source MAC addresses, plus a counter of the number of different source MAC addresses.
- When adding a new source MAC address to the list, if the number of MAC addresses pushes past the configured maximum, a port security violation has occurred. The switch takes action (the default action is to shutdown the interface).

While those rules define the basics, port security allows other options as well, including letting you configure the specific MAC address(es) allowed to send frames in an interface. For example, in Figure 8-7, switch SW1 connects through interface F0/1 to PC1, so the port security configuration could list PC1's MAC address as the specific allowed MAC address. But predefining MAC addresses for port security is optional: You can predefine all MAC addresses, none, or a subset of the MAC addresses.

You might like the idea of predefining the MAC addresses for port security, but finding the MAC address of each device can be a bother. Port security provides an easy way to discover the MAC addresses used off each port using a feature called *sticky secure MAC addresses*. With this feature, port security learns the MAC addresses off each port and stores those in the port security configuration (in the running-config file). This feature helps reduce the big effort of finding out the MAC address of each device.

As you can see, port security has a lot of detailed options. The next few sections walk you through these options to pull the ideas together.

Configuring Port Security

Port security configuration involves several steps. First, you need to disable the negotiation of a feature that is not discussed until Chapter 9: whether the port is an access or trunk port. For now, accept that port security requires a port to be configured to either be an access port or a trunking port. The rest of the commands enable port security, set the maximum allowed MAC addresses per port, and configure the actual MAC addresses, as detailed in this list:

Key Topic

Step 1. Make the switch interface either a static access or trunk interface, using the **switchport mode access** or the **switchport mode trunk** interface subcommands, respectively.

Step 2. Enable port security using the **switchport port-security** interface subcommand.

Step 3. (Optional) Override the default maximum number of allowed MAC addresses associated with the interface (1) by using the **switchport port-security maximum** *number* interface subcommand.

Step 4. (Optional) Override the default action to take upon a security violation (shutdown) using the **switchport port-security violation** {**protect** | **restrict** | **shutdown**} interface subcommand.

Step 5. (Optional) Predefine any allowed source MAC address(es) for this interface, using the **switchport port-security mac-address** *mac-address* command. Use the command multiple times to define more than one MAC address.

Step 6. (Optional) Tell the switch to "sticky learn" dynamically learned MAC addresses with the **switchport port-security mac-address sticky** interface subcommand.

Figure 8-8 and Example 8-13 show four examples of port security, each with different details just to show the different options.

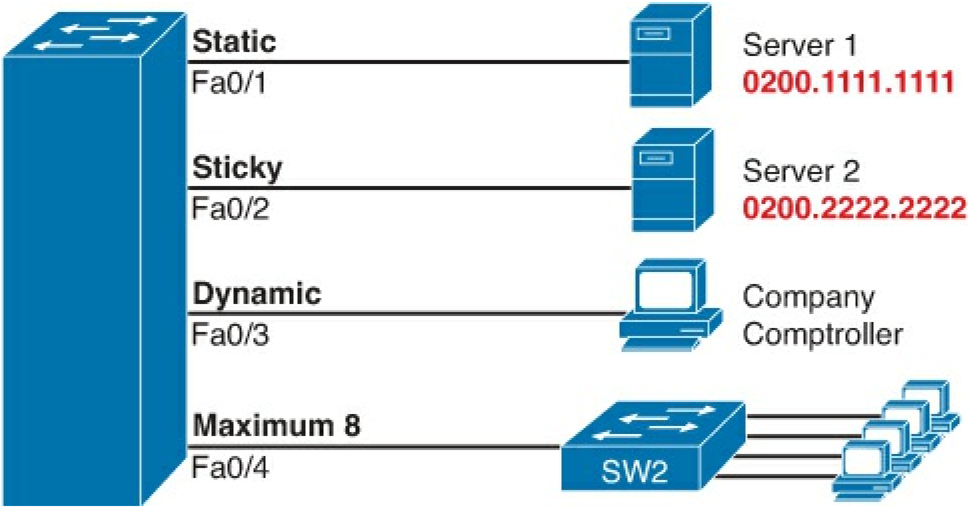


Figure 8-8. Port Security Configuration Example

Example 8-13. Variations on Port Security Configuration

Click here to view code image

```
SW1# show running-config
(Lines omitted for brevity)

interface FastEthernet0/1
switchport mode access
switchport port-security
switchport port-security mac-address 0200.1111.1111
!
interface FastEthernet0/2
switchport mode access
switchport port-security
switchport port-security mac-address sticky
!
interface FastEthernet0/3
switchport mode access
switchport port-security
!
interface FastEthernet0/4
switchport mode access
switchport port-security
switchport port-security maximum 8
```

First, scan the configuration for all four interfaces in Example 8-13, focusing on the first two interface subcommands. Note that all four interfaces in the example use the same first two interface subcommands, matching the first two configuration steps noted before Figure 8-8. The **switchport port-security** command enables port security, with all defaults, with the **switchport mode access** command meeting the requirement to configure the port as either an access or trunk port.

Next, scan all four interfaces again, and note that the configuration differs on each interface after those first two interface subcommands. Each interface simply shows a different example for perspective.

The first interface, FastEthernet 0/1, adds one optional port security subcommand: **switchport port-security mac-address 0200.1111.1111**, which defines a specific source MAC address. With the default maximum source address setting of 1, only frames with source MAC 0200.1111.1111 will be allowed in this port. When a frame with a source other than 0200.1111.1111 enters F0/1, the switch will take the default violation action and disable the interface.

As a second example, FastEthernet 0/2 uses the same logic as FastEthernet 0/1, except that it uses the sticky learning feature instead of predefining a MAC address with the **switchport port-security mac-address sticky** command. The end of upcoming Example 8-14 shows the running config file that lists the sticky-learned MAC address in this case.

> **Note**
>
> Port security does not save the configuration of the sticky addresses, so use the **copy running-config startup-config** command if desired.

The other two interfaces do not predefine MAC addresses, nor do they sticky-learn the MAC addresses. The only difference between these two interfaces' port security configuration is that FastEthernet 0/4 supports eight MAC addresses, because it connects to another switch and should receive frames with multiple source MAC addresses. Interface F0/3 uses the default maximum of one MAC address.

Verifying Port Security

Example 8-14 lists the output of two examples of the **show port-security interface** command. This command lists the configuration settings for port security on an interface, plus it lists several important facts about the current operation of port security, including information about any security violations. The two commands in the example show interfaces F0/1 and F0/2, based on Example 8-13's configuration.

Example 8-14. Using Port Security to Define Correct MAC Addresses of Particular Interfaces

Click here to view code image

```
SW1# show port-security interface fastEthernet 0/1
Port Security : Enabled
Port Status : Secure-shutdown
Violation Mode : Shutdown
Aging Time : 0 mins
Aging Type : Absolute
SecureStatic Address Aging : Disabled
Maximum MAC Addresses : 1
Total MAC Addresses : 1
Configured MAC Addresses : 1
```

```
Sticky MAC Addresses : 0
Last Source Address:Vlan : 0013.197b.5004:1
Security Violation Count : 1

SW1# show port-security interface fastEthernet 0/2
Port Security : Enabled
Port Status : Secure-up
Violation Mode : Shutdown
Aging Time : 0 mins
Aging Type : Absolute
SecureStatic Address Aging : Disabled
Maximum MAC Addresses : 1
Total MAC Addresses : 1
Configured MAC Addresses : 1
Sticky MAC Addresses : 1
Last Source Address:Vlan : 0200.2222.2222:1
Security Violation Count : 0

SW1# show running-config
(Lines omitted for brevity)
interface FastEthernet0/2
switchport mode access
switchport port-security
switchport port-security mac-address sticky
switchport port-security mac-address sticky 0200.2222.2222
```

The first two commands in Example 8-14 confirm that a security violation has occurred on FastEthernet 0/1, but no violations have occurred on FastEthernet 0/2. The **show port-security interface fastethernet 0/1** command shows that the interface is in a *secure-shutdown* state, which means that the interface has been disabled because of port security. In this case, another device connected to port F0/1, sending a frame with a source MAC address other than 0200.1111.1111, is causing a violation. However, port Fa0/2, which used sticky learning, simply learned the MAC address used by Server 2.

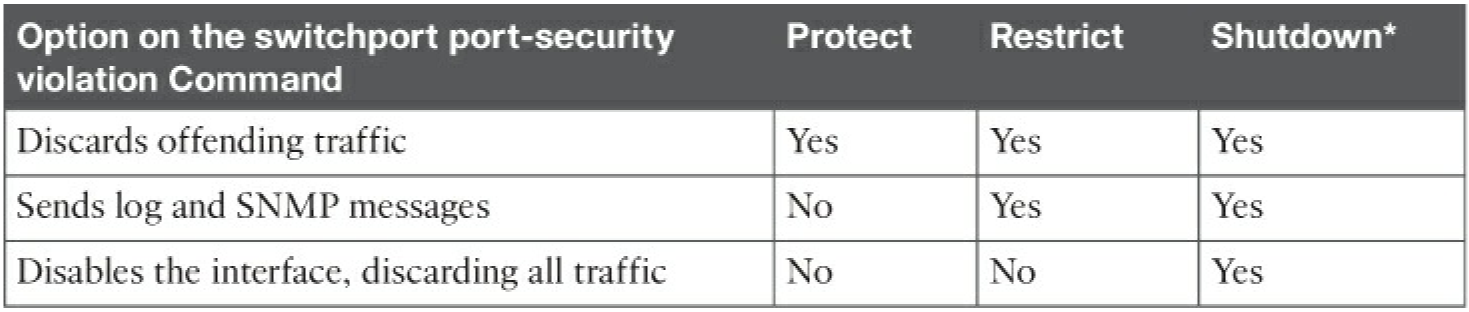
The bottom of Example 8-14, as compared to the configuration in Example 8-13, shows the changes in the running-config because of sticky learning, with the **switchport port-security mac-address sticky 0200.2222.2222** interface subcommand.

Port Security Actions

Finally, the switch can be configured to use one of three actions when a violation occurs. All three options cause the switch to discard the offending frame, but some of the options make the switch take additional actions. The actions include the sending of syslog messages to the console, sending SNMP trap messages to the network management station, and disabling the interface. Table 8-4 lists the options of the **switchport port-security violation {protect | restrict | shutdown}** command and their meanings.

Key Topic

Table 8-4. Actions When Port Security Violation Occurs



Option on the switchport port-security violation Command	Protect	Restrict	Shutdown*
Discards offending traffic	Yes	Yes	Yes
Sends log and SNMP messages	No	Yes	Yes
Disables the interface, discarding all traffic	No	No	Yes

Note that the shutdown option does not actually add the **shutdown** subcommand to the interface configuration. Instead, IOS puts the interface in an *error disabled* (err-disabled) state, which makes the switch stop all inbound and outbound frames. To recover from this state, someone must manually disable the interface with the **shutdown** interface command and then enable the interface with the **no shutdown** command.

Securing Unused Switch Interfaces

The default settings on Cisco switches work great if you want to buy a switch, unbox it, plug it in, and have it immediately work without any other effort. Those same defaults have an unfortunate side effect for worse security. With all default configuration, unused interfaces might be used by an attacker to gain access to the LAN. So, Cisco makes some general recommendations to override the default interface settings to make the unused ports more secure, as follows:

- Administratively disable the interface using the **shutdown** interface subcommand.
- Prevent VLAN trunking by making the port a nontrunking interface using the **switchport mode access** interface subcommand.
- Assign the port to an unused VLAN using the **switchport access vlan** *number* interface subcommand.
- Set the native VLAN to not be VLAN 1, but to instead be an unused VLAN, using the **switchport trunk native vlan** *vlan-id* interface subcommand. (The native VLAN is discussed in Chapter 9.)

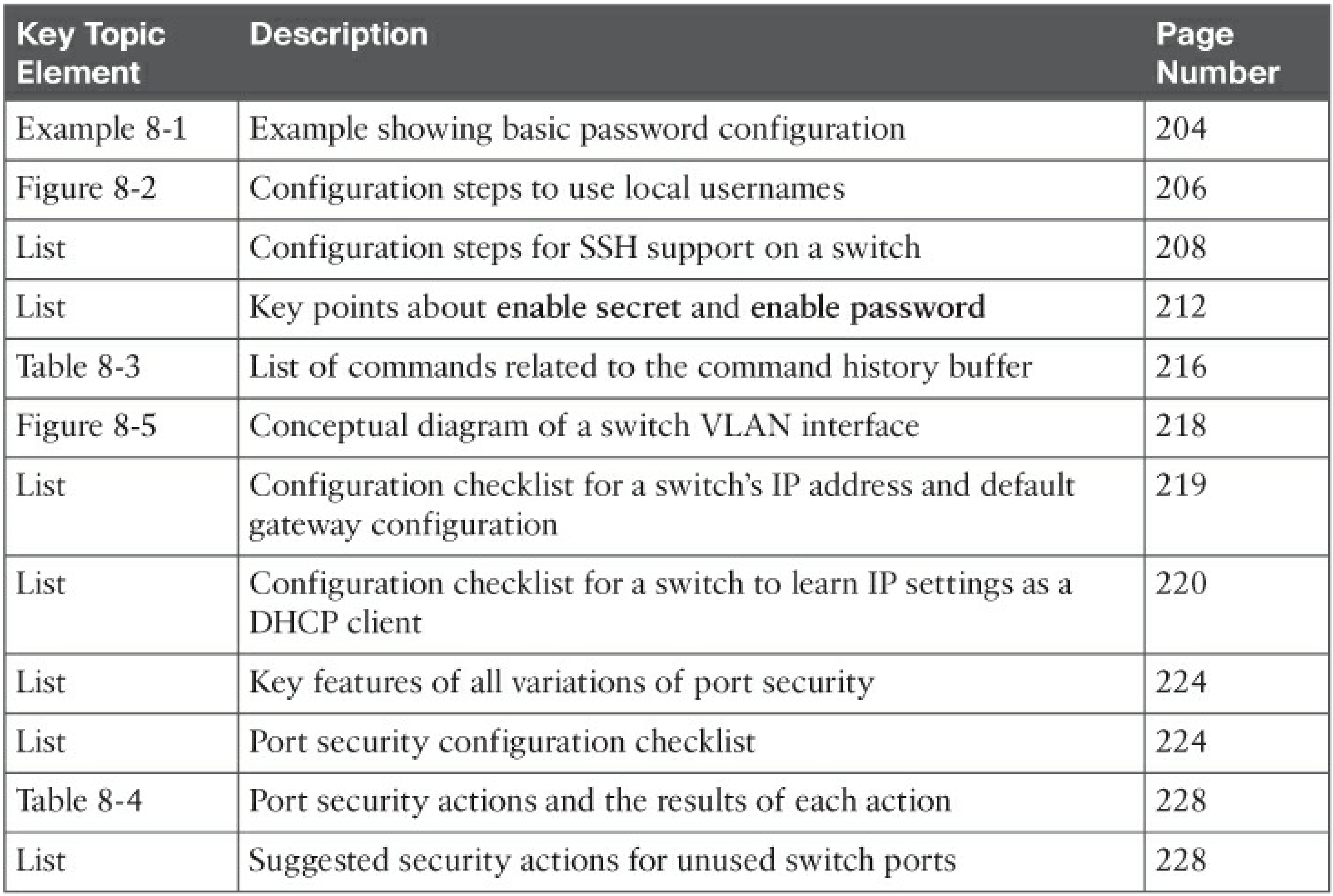
Frankly, if you just shutdown the interface, the security exposure goes away, but the other tasks prevent any immediate problems if someone else comes around and enables the interface by configuring a **no shutdown** command.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 8-5 lists these key topics and shows where each is discussed.

Table 8-5. Key Topics for Chapter 8



Key Topic Element	Description	Page Number
Example 8-1	Example showing basic password configuration	204
Figure 8-2	Configuration steps to use local usernames	206
List	Configuration steps for SSH support on a switch	208
List	Key points about **enable secret** and **enable password**	212
Table 8-3	List of commands related to the command history buffer	216
Figure 8-5	Conceptual diagram of a switch VLAN interface	218
List	Configuration checklist for a switch's IP address and default gateway configuration	219
List	Configuration checklist for a switch to learn IP settings as a DHCP client	220
List	Key features of all variations of port security	224
List	Port security configuration checklist	224
Table 8-4	Port security actions and the results of each action	228
List	Suggested security actions for unused switch ports	228

Note

There is no need to memorize any configuration step list referenced as a key topic; these lists are just study aids.

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists for you to check your work.

Definitions of Key Terms

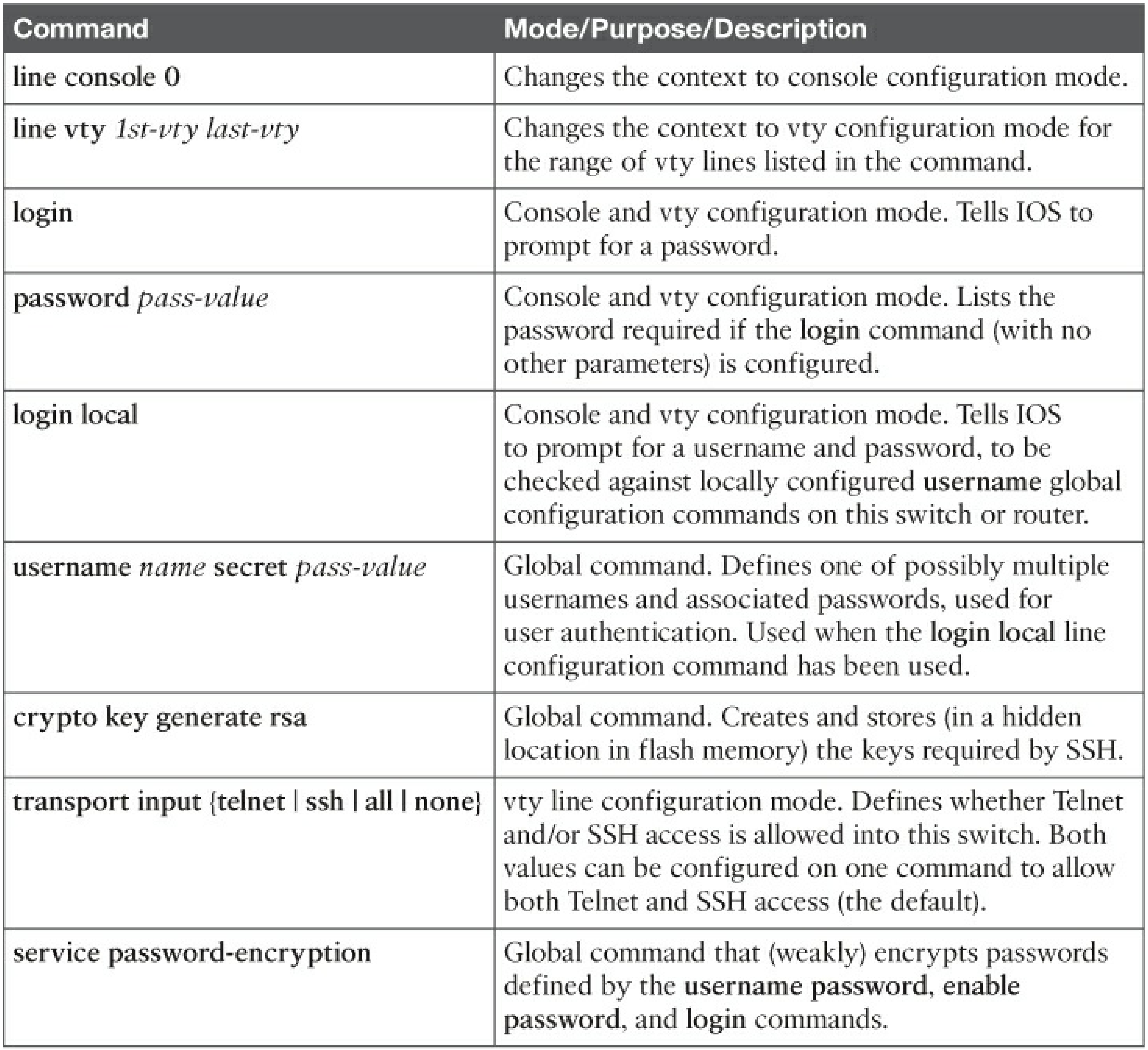
After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

Telnet
SSH
local username
VLAN interface
port security

Command References

Tables 8-6 though 8-10 list the configuration commands used in this chapter, by general topic. Table 8-11, at the very end of the chapter, lists the EXEC commands from this chapter.

Table 8-6. Console, Telnet, and SSH Login Commands

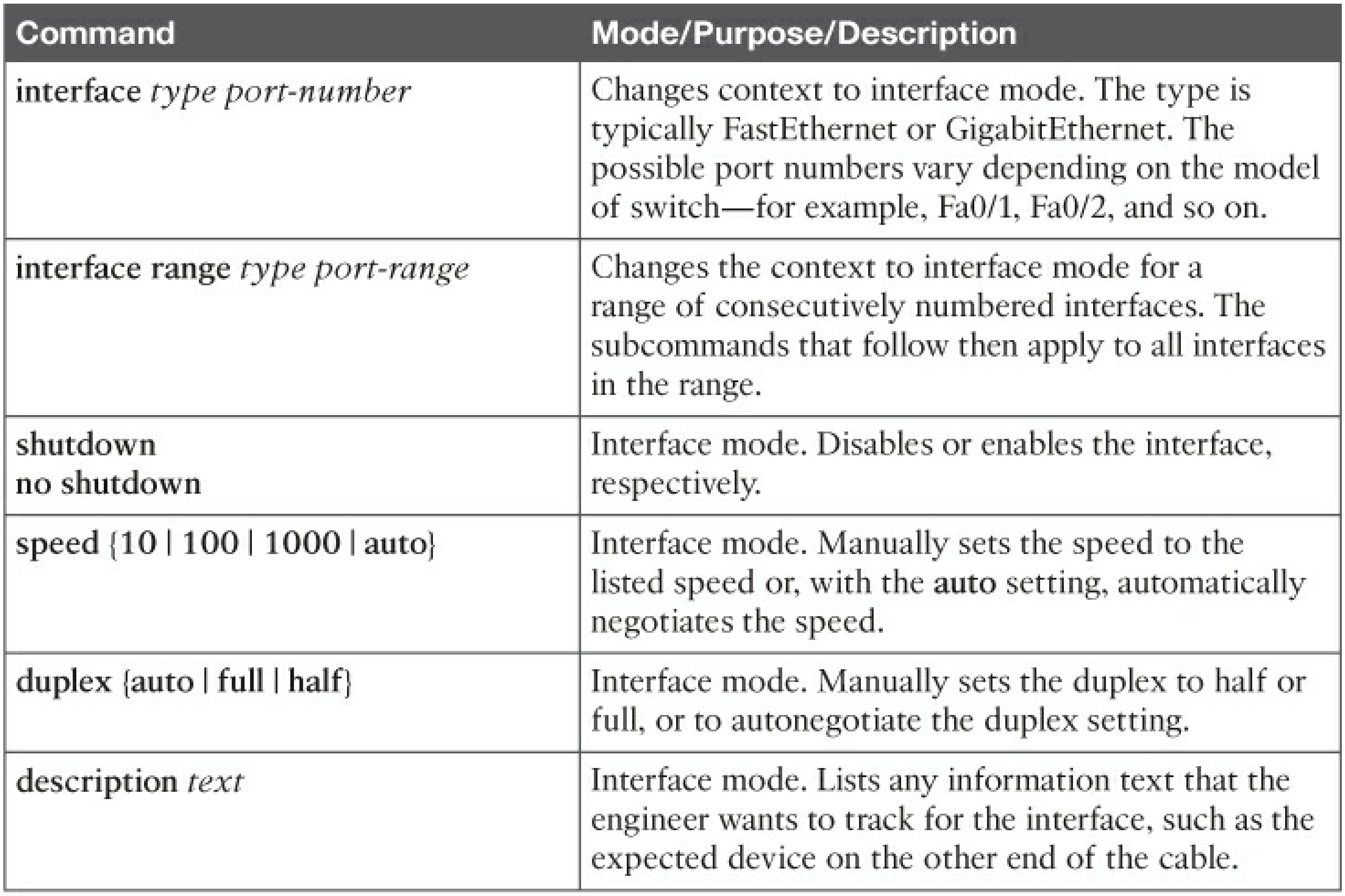


Command	Mode/Purpose/Description
line console 0	Changes the context to console configuration mode.
line vty *1st-vty last-vty*	Changes the context to vty configuration mode for the range of vty lines listed in the command.
login	Console and vty configuration mode. Tells IOS to prompt for a password.
password *pass-value*	Console and vty configuration mode. Lists the password required if the **login** command (with no other parameters) is configured.
login local	Console and vty configuration mode. Tells IOS to prompt for a username and password, to be checked against locally configured **username** global configuration commands on this switch or router.
username *name* **secret** *pass-value*	Global command. Defines one of possibly multiple usernames and associated passwords, used for user authentication. Used when the **login local** line configuration command has been used.
crypto key generate rsa	Global command. Creates and stores (in a hidden location in flash memory) the keys required by SSH.
transport input {**telnet** | **ssh** | **all** | **none**}	vty line configuration mode. Defines whether Telnet and/or SSH access is allowed into this switch. Both values can be configured on one command to allow both Telnet and SSH access (the default).
service password-encryption	Global command that (weakly) encrypts passwords defined by the **username password**, **enable password**, and **login** commands.

Table 8-7. Switch IPv4 Configuration

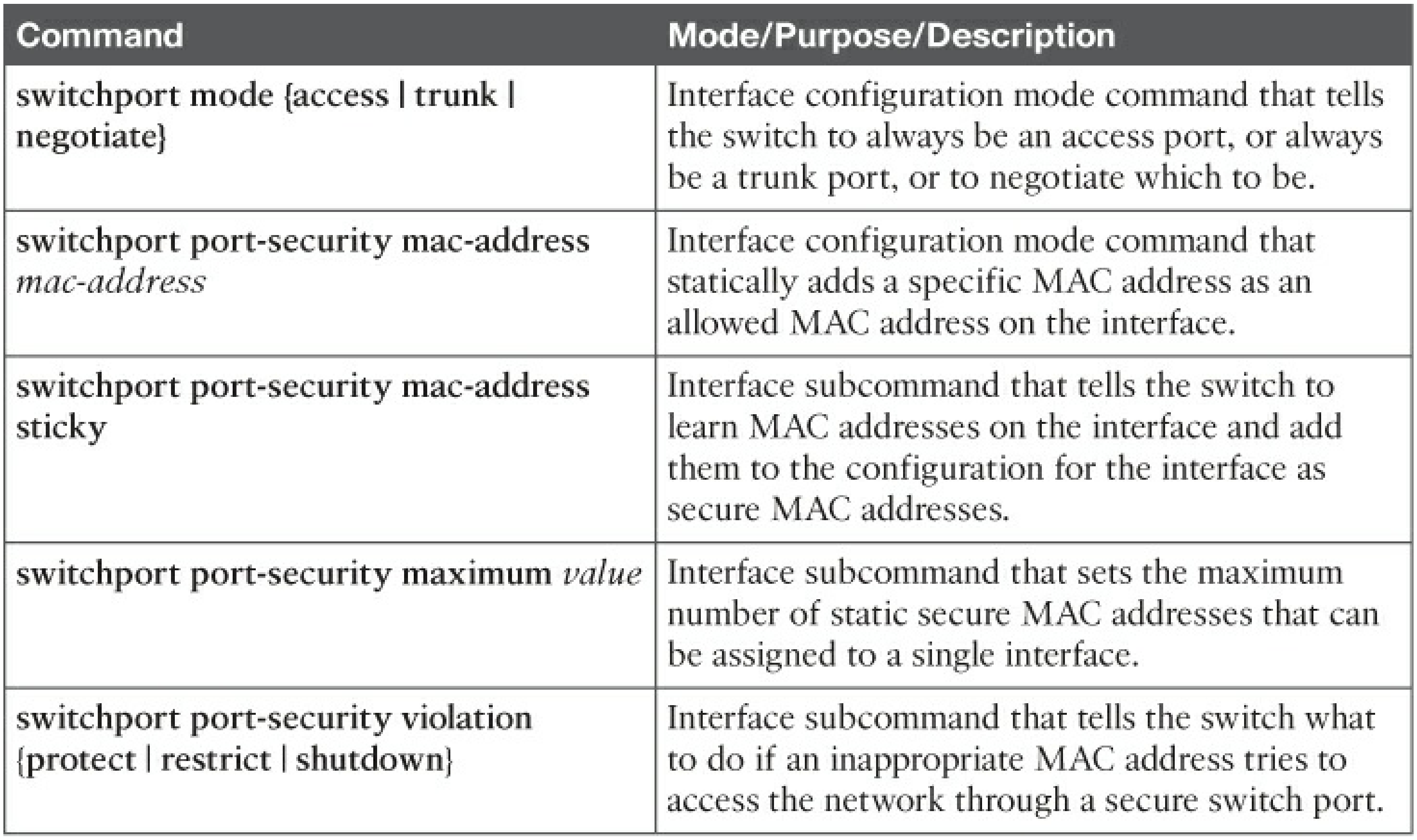
Command	Mode/Purpose/Description
interface vlan *number*	Changes the context to VLAN interface mode. For VLAN 1, allows the configuration of the switch's IP address.
ip address *ip-address subnet-mask*	VLAN interface mode. Statically configures the switch's IP address and mask.
ip address dhcp	VLAN interface mode. Configures the switch as a DHCP client to discover its IP address, mask, and default gateway.
ip default-gateway *address*	Global command. Configures the switch's default gateway IP address. Not required if the switch uses DHCP.
ip name-server *server-ip-1 server-ip-2 …*	Global command. Configures the IP address(es) of DNS servers, so any commands when logged into the switch will use the DNS for name resolution.

Table 8-8. Switch Interface Configuration



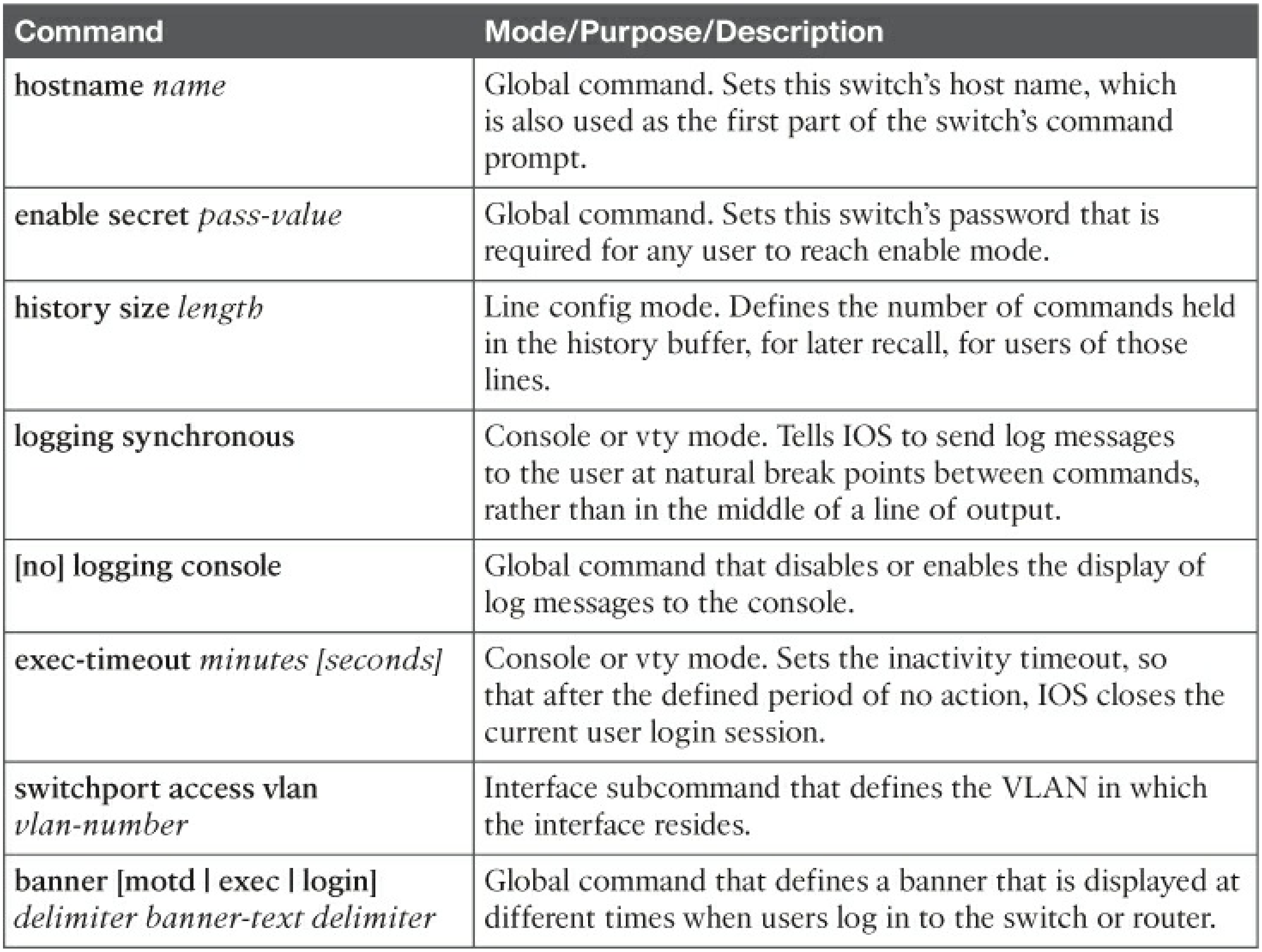
Command	Mode/Purpose/Description
interface *type port-number*	Changes context to interface mode. The type is typically FastEthernet or GigabitEthernet. The possible port numbers vary depending on the model of switch—for example, Fa0/1, Fa0/2, and so on.
interface range *type port-range*	Changes the context to interface mode for a range of consecutively numbered interfaces. The subcommands that follow then apply to all interfaces in the range.
shutdown **no shutdown**	Interface mode. Disables or enables the interface, respectively.
speed {**10** | **100** | **1000** | **auto**}	Interface mode. Manually sets the speed to the listed speed or, with the **auto** setting, automatically negotiates the speed.
duplex {**auto** | **full** | **half**}	Interface mode. Manually sets the duplex to half or full, or to autonegotiate the duplex setting.
description *text*	Interface mode. Lists any information text that the engineer wants to track for the interface, such as the expected device on the other end of the cable.

Table 8-9. Port Security



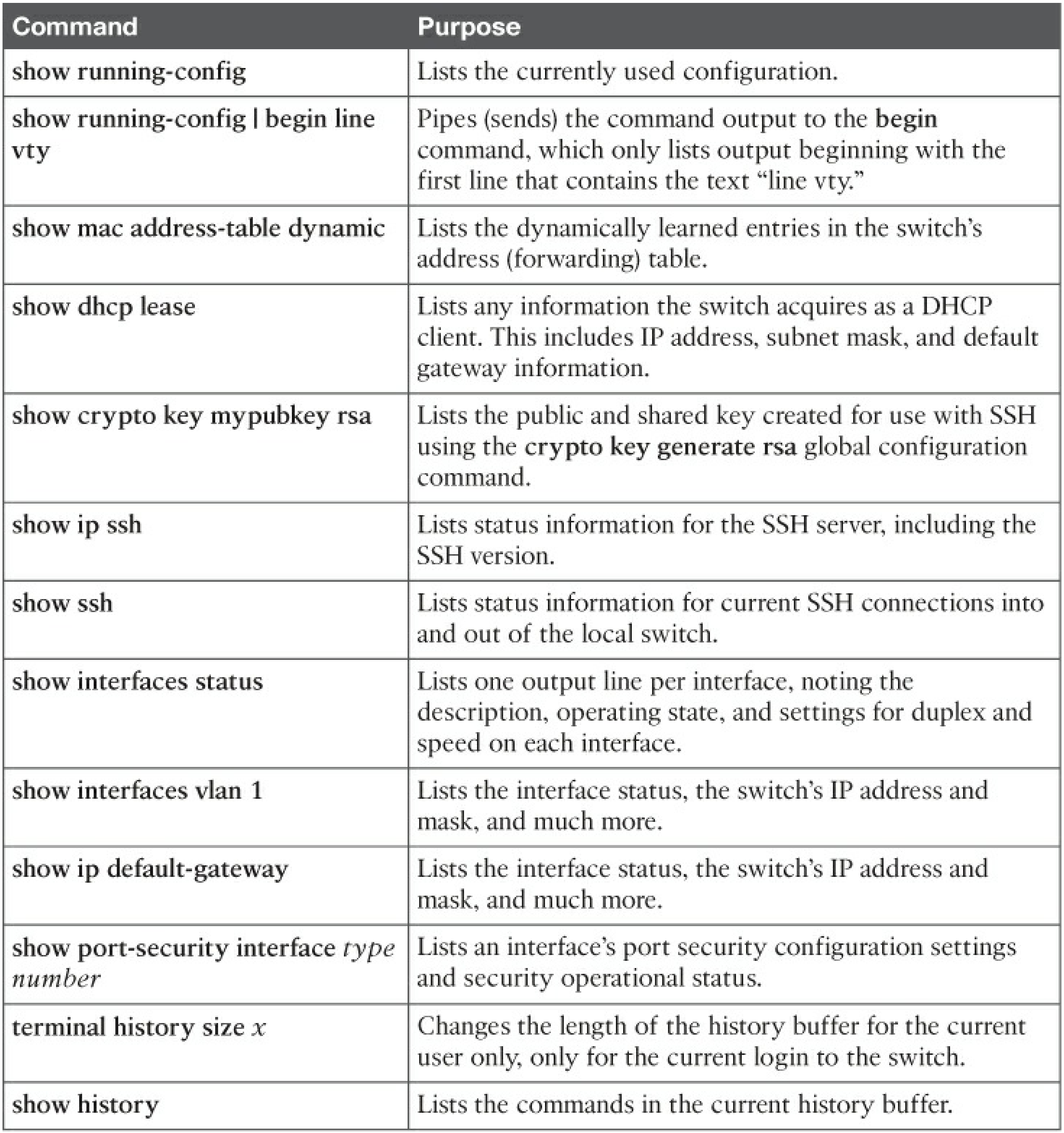
Command	Mode/Purpose/Description
switchport mode {access | trunk | negotiate}	Interface configuration mode command that tells the switch to always be an access port, or always be a trunk port, or to negotiate which to be.
switchport port-security mac-address *mac-address*	Interface configuration mode command that statically adds a specific MAC address as an allowed MAC address on the interface.
switchport port-security mac-address sticky	Interface subcommand that tells the switch to learn MAC addresses on the interface and add them to the configuration for the interface as secure MAC addresses.
switchport port-security maximum *value*	Interface subcommand that sets the maximum number of static secure MAC addresses that can be assigned to a single interface.
switchport port-security violation {**protect** | **restrict** | **shutdown**}	Interface subcommand that tells the switch what to do if an inappropriate MAC address tries to access the network through a secure switch port.

Table 8-10. Other Switch Configuration



Command	Mode/Purpose/Description
hostname *name*	Global command. Sets this switch's host name, which is also used as the first part of the switch's command prompt.
enable secret *pass-value*	Global command. Sets this switch's password that is required for any user to reach enable mode.
history size *length*	Line config mode. Defines the number of commands held in the history buffer, for later recall, for users of those lines.
logging synchronous	Console or vty mode. Tells IOS to send log messages to the user at natural break points between commands, rather than in the middle of a line of output.
[no] logging console	Global command that disables or enables the display of log messages to the console.
exec-timeout *minutes [seconds]*	Console or vty mode. Sets the inactivity timeout, so that after the defined period of no action, IOS closes the current user login session.
switchport access vlan *vlan-number*	Interface subcommand that defines the VLAN in which the interface resides.
banner [motd | exec | login] *delimiter banner-text delimiter*	Global command that defines a banner that is displayed at different times when users log in to the switch or router.

Table 8-11. Chapter 8 EXEC Command Reference



Command	Purpose
show running-config	Lists the currently used configuration.
show running-config | begin line vty	Pipes (sends) the command output to the **begin** command, which only lists output beginning with the first line that contains the text “line vty.”
show mac address-table dynamic	Lists the dynamically learned entries in the switch’s address (forwarding) table.
show dhcp lease	Lists any information the switch acquires as a DHCP client. This includes IP address, subnet mask, and default gateway information.
show crypto key mypubkey rsa	Lists the public and shared key created for use with SSH using the **crypto key generate rsa** global configuration command.
show ip ssh	Lists status information for the SSH server, including the SSH version.
show ssh	Lists status information for current SSH connections into and out of the local switch.
show interfaces status	Lists one output line per interface, noting the description, operating state, and settings for duplex and speed on each interface.
show interfaces vlan 1	Lists the interface status, the switch’s IP address and mask, and much more.
show ip default-gateway	Lists the interface status, the switch’s IP address and mask, and much more.
show port-security interface *type number*	Lists an interface’s port security configuration settings and security operational status.
terminal history size *x*	Changes the length of the history buffer for the current user only, only for the current login to the switch.
show history	Lists the commands in the current history buffer.

Chapter 9. Implementing Ethernet Virtual LANs

This chapter covers the following exam topics:

- **Operation of IP Data Networks**
  - Predict the data flow between two hosts across a network.
- **LAN Switching Technologies**
  - Identify basic switching concepts and the operation of Cisco switches.
    - Broadcast Domains
    - CAM Table
  - Describe how VLANs create logically separate networks and the need for routing between them.
  - Explain network segmentation and basic traffic management concepts
  - Configure and verify VLANs
  - Configure and verify trunking on Cisco switches
    - DTP
- **Troubleshooting**
  - Troubleshoot and Resolve VLAN problems
    - Identify that VLANs are configured
    - Port membership correct
    - IP address configured
  - Troubleshoot and Resolve trunking problems on Cisco switches
    - Correct trunk states
    - Correct encapsulation configured
    - Correct vlans allowed

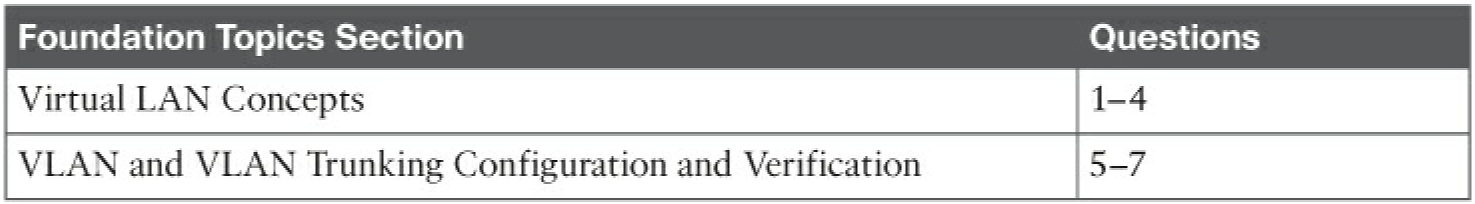
At their heart, Ethernet switches receive Ethernet frames, make decisions, and then forward (switch) those Ethernet frames. That core logic revolves around MAC addresses, the interface in which the frame arrives, and the interface(s) out which the switch forwards the frame. Several switch features have some impact on an individual switch's decisions about where to forward frames, but of all the topics in this book, virtual LANs (VLAN) easily have the biggest impact on those choices.

This chapter examines the concepts and configuration of VLANs. The first major section of the chapter explains the core concepts. These concepts include how VLANs work on a single switch, how to use VLAN trunking to create VLANs that span across multiple switches, and how to forward traffic between VLANs using a router. The second major section shows how to configure VLANs and VLAN trunks: how to statically assign interfaces to a VLAN.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 9-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Virtual LAN Concepts	1–4
VLAN and VLAN Trunking Configuration and Verification	5–7

1. In a LAN, which of the following terms best equates to the term *VLAN*?
   - **a.** Collision domain
   - **b.** Broadcast domain
   - **c.** Subnet
   - **d.** Single switch
   - **e.** Trunk
2. Imagine a switch with three configured VLANs. How many IP subnets are required, assuming that all hosts in all VLANs want to use TCP/IP?
   - **a.** 0
   - **b.** 1
   - **c.** 2

d. 3

e. You can't tell from the information provided.

3. Switch SW1 sends a frame to switch SW2 using 802.1Q trunking. Which of the answers describes how SW1 changes or adds to the Ethernet frame before forwarding the frame to SW2?

a. Inserts a 4-byte header and does change the MAC addresses

b. Inserts a 4-byte header and does not change the MAC addresses

c. Encapsulates the original frame behind an entirely-new Ethernet header

d. None of the other answers are correct

4. For an 802.1Q trunk between two Ethernet switches, which answer most accurately defines which frames do not include an 802.1Q header?

a. Frames in the native VLAN (only one)

b. Frames in extended VLANs

c. Frames in VLAN 1 (not configurable)

d. Frames in all native VLANs (multiple allowed)

5. Imagine that you are told that switch 1 is configured with the **dynamic auto** parameter for trunking on its Fa0/5 interface, which is connected to switch 2. You have to configure switch 2. Which of the following settings for trunking could allow trunking to work? (Choose two answers.)

a. Trunking turned **on**

b. dynamic auto

c. dynamic desirable

d. access

e. None of the other answers are correct.

6. A switch has just arrived from Cisco. The switch has never been configured with any VLANs, but VTP has been disabled. An engineer gets into configuration mode and issues the **vlan 22** command, followed by the **name Hannahs-VLAN** command. Which of the following are true? (Choose two answers.)

a. VLAN 22 is listed in the output of the **show vlan brief** command.

b. VLAN 22 is listed in the output of the **show running-config** command.

c. VLAN 22 is not created by this process.

d. VLAN 22 does not exist in that switch until at least one interface is assigned to that VLAN.

7. Which of the following commands identify switch interfaces as being trunking interfaces: interfaces that currently operate as VLAN trunks? (Choose two answers.)

a. show interfaces

b. show interfaces switchport

c. show interfaces trunk

d. show trunks

Answers to the "Do I Know This Already?" quiz:

1 B **2** D **3** B **4** A **5** A and C **6** A and B **7** B and C

Foundation Topics

Virtual LAN Concepts

Before understanding VLANs, you must first have a specific understanding of the definition of a LAN. For example, from one perspective, a LAN includes all the user devices, servers, switches, routers, cables, and wireless access points in one location. However, an alternative narrower definition of a LAN can help in understanding the concept of a virtual LAN:

> A LAN includes all devices in the same broadcast domain.

A broadcast domain includes the set of all LAN-connected devices, so that when any of the devices sends a broadcast frame, all the other devices get a copy of the frame. So, from one perspective, you can think of a LAN and a broadcast domain as being basically the same thing.

Without VLANs, a switch considers all its interfaces to be in the same broadcast domain. That is, for one switch, when a broadcast frame entered one switch port, the switch forwarded that broadcast frame out all other ports. With that logic, to create two different LAN broadcast domains, you had to buy two different Ethernet LAN switches, as shown in Figure 9-1.

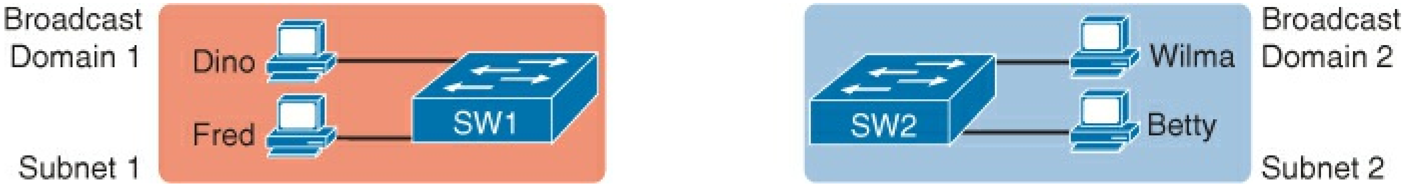


Figure 9-1. Creating Two Broadcast Domains with Two Physical Switches and No VLANs

With support for VLANs, a single switch can accomplish the same goals of the design in Figure 9-1—to create two broadcast domains—with a single switch. With VLANs, a switch can configure some interfaces into one broadcast domain and some into another, creating multiple broadcast domains. These individual broadcast domains created by the switch are called *virtual LANs (VLAN)*.

For example, in Figure 9-2, the single switch creates two VLANs, treating the ports in each VLAN as being completely separate. The switch would never forward a frame sent by Dino (in VLAN 1) over to either Wilma or Betty (in VLAN 2).

Key Topic

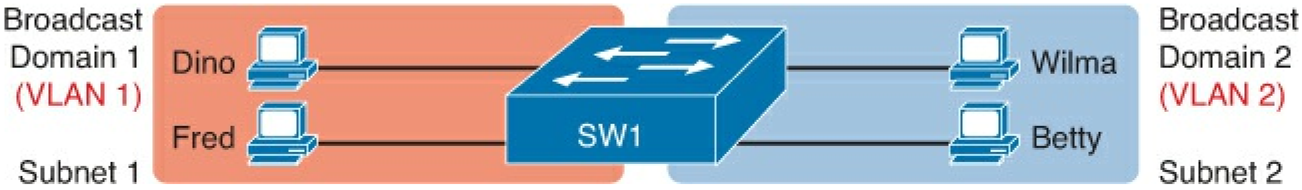


Figure 9-2. Creating Two Broadcast Domains Using One Switch and VLANs

Designing campus LANs to use more VLANs, each with a smaller number of devices, often helps improve the LAN in many ways. For example, a broadcast sent by one host in a VLAN will be received and processed by all the other hosts in the VLAN—but not by hosts in a different VLAN. Limiting the number of hosts that receive a single broadcast frame reduces the number of hosts that waste effort processing unneeded broadcasts. It also reduces security risks, because fewer hosts see frames sent by any one host. These are just a few reasons for separating hosts into different VLANs. The following list summarizes the most common reasons for choosing to create smaller broadcast domains (VLANs):

Key Topic

- To reduce CPU overhead on each device by reducing the number of devices that receive each broadcast frame
- To reduce security risks by reducing the number of hosts that receive copies of frames that the switches flood (broadcasts, multicasts, and unknown unicasts)
- To improve security for hosts that send sensitive data by keeping those hosts on a separate VLAN
- To create more flexible designs that group users by department, or by groups that work together, instead of by physical location
- To solve problems more quickly, because the failure domain for many problems is the same set of devices as those in the same broadcast domain
- To reduce the workload for the Spanning Tree Protocol (STP) by limiting a VLAN to a single access switch

This chapter does not examine all the reasons for VLANs in more depth. However, know that most enterprise networks use VLANs quite a bit. The rest of this chapter looks closely at the mechanics of how VLANs work across multiple Cisco switches, including the required configuration. To that end, the next section examines VLAN trunking, a feature required when installing a VLAN that exists on more than one LAN switch.

Creating Multiswitch VLANs Using Trunking

Configuring VLANs on a single switch requires only a little effort: You simply configure each port to tell it the VLAN number to which the port belongs. With multiple switches, you have to consider additional concepts about how to forward traffic between the switches.

When using VLANs in networks that have multiple interconnected switches, the switches need to use *VLAN trunking* on the links between the switches. VLAN trunking causes the switches to use a process called *VLAN tagging*, by which the sending switch adds another header to the frame before sending it over the trunk. This extra trunking header includes a *VLAN identifier* (VLAN ID) field so that the sending switch can associate the frame with a particular VLAN ID, and the receiving switch can then know in what VLAN each frame belongs.

Figure 9-3 shows an example that demonstrates VLANs that exist on multiple switches, but it does not use trunking. First, the design uses two VLANs: VLAN 10 and VLAN 20. Each switch has two ports assigned to each VLAN, so each VLAN exists in both switches. To forward traffic in VLAN 10 between the two switches, the design includes a link between switches, with that link fully inside VLAN 10. Likewise, to support VLAN 20 traffic between switches, the design uses a second link between switches, with that link inside VLAN 20.

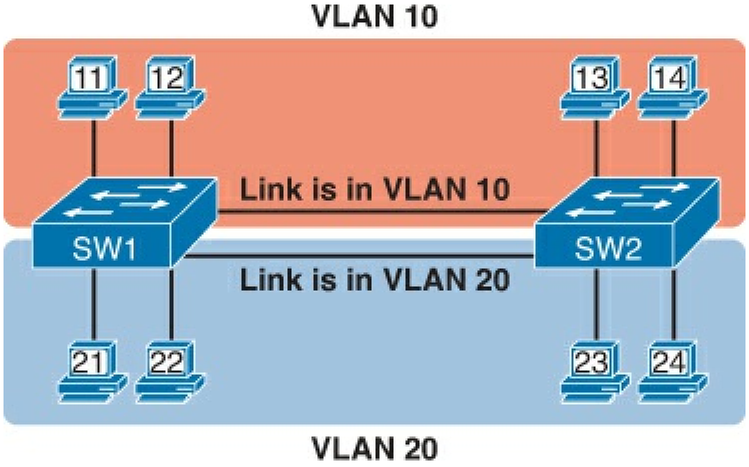


Figure 9-3. Multiswitch VLAN Without VLAN Trunking

The design in Figure 9-3 functions perfectly. For example, PC11 (in VLAN 10) can send a frame to PC14. The frame flows into SW1, over the top link (the one that is in VLAN 10) and over to SW2.

The design shown in Figure 9-3 works, but it simply does not scale very well. It requires one physical link between switches to support every VLAN. If a design needed 10 or 20 VLANs, you would need 10 or 20 links between switches, and you would use 10 or 20 switch ports (on each switch) for those links.

VLAN Tagging Concepts

VLAN trunking creates one link between switches that supports as many VLANs as you need. As a VLAN trunk, the switches treat the link as if it were a part of all the VLANs. At the same time, the trunk keeps the VLAN traffic separate, so frames in VLAN 10 would not go to devices in VLAN 20, and vice versa, because each frame is identified by VLAN number as it crosses the trunk. Figure 9-4 shows the idea, with a single physical link between the two switches.

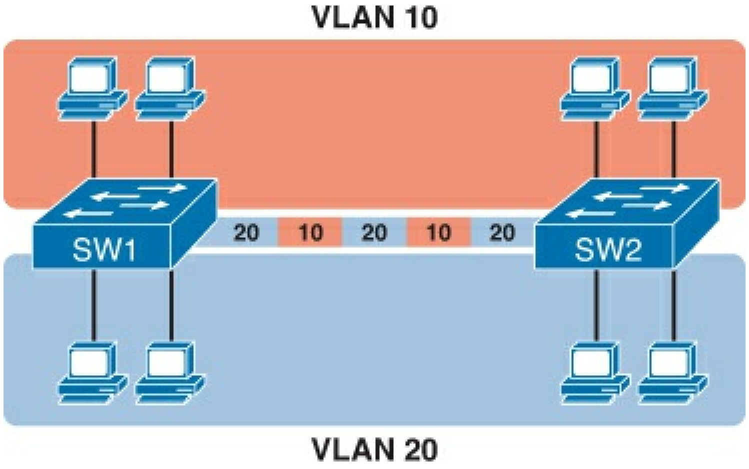


Figure 9-4. Multiswitch VLAN with Trunking

The use of trunking allows switches to pass frames from multiple VLANs over a single physical connection by adding a small header to the Ethernet frame. For example, Figure 9-5 shows PC11 sending a broadcast frame on interface Fa0/1 at Step 1. To flood the frame, switch SW1 needs to forward the broadcast frame to switch SW2. However, SW1 needs to let SW2 know that the frame is part of VLAN 10, so that after the frame is received, SW2 will flood the frame only into VLAN 10, and not into VLAN 20. So, as shown at Step 2, before sending the frame, SW1 adds a VLAN header to the original Ethernet frame, with the VLAN header listing a VLAN ID of 10 in this case.

Key Topic

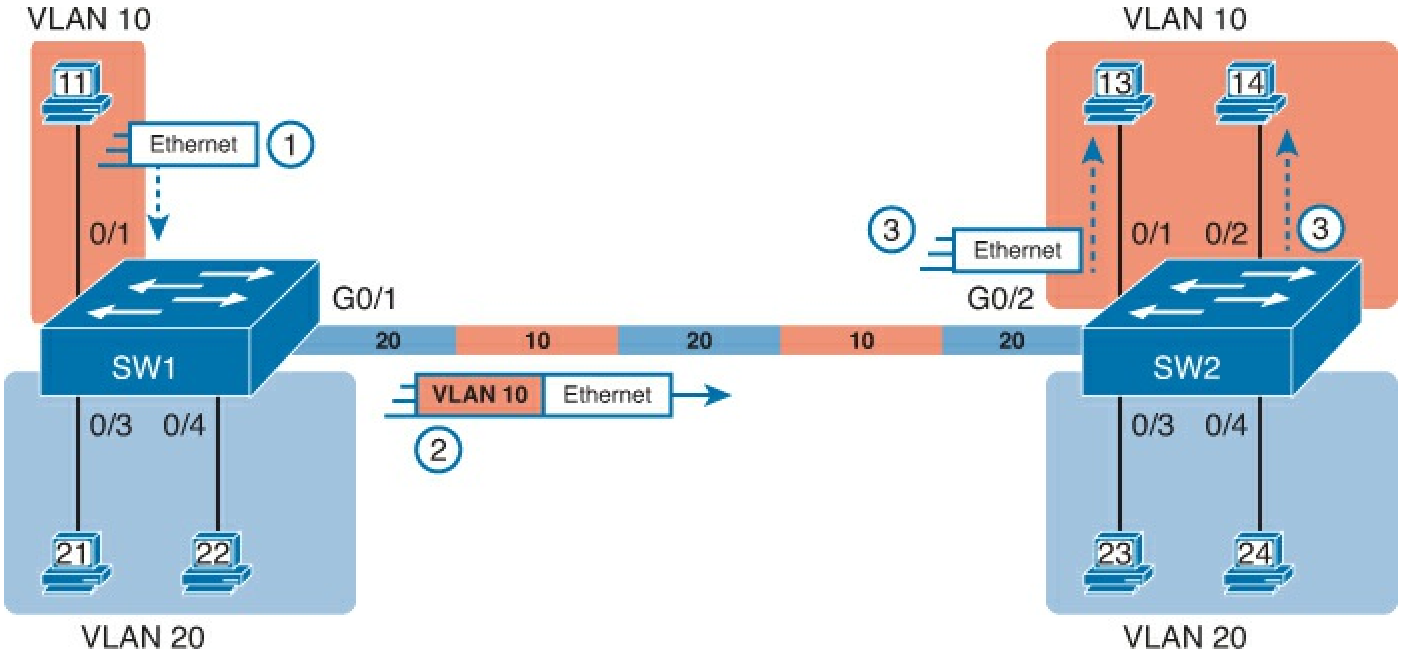


Figure 9-5. VLAN Trunking Between Two Switches

When SW2 receives the frame, it understands that the frame is in VLAN 10. SW2 then removes the VLAN header, forwarding the original frame out its interfaces in VLAN 10 (Step 3).

For another example, consider the case when PC21 (in VLAN 20) sends a broadcast. SW1 sends the broadcast out port Fa0/4 (because that port is in VLAN 20) and out Gi0/1 (because it is a trunk, meaning that it supports multiple different VLANs). SW1 adds a trunking header to the frame, listing a VLAN ID of 20. SW2 strips off the trunking header after noticing that the frame is part of VLAN 20, so SW2 knows to forward the frame out only ports Fa0/3 and Fa0/4, because they are in VLAN 20, and not out ports Fa0/1 and Fa0/2, because they are in VLAN 10.

The 802.1Q and ISL VLAN Trunking Protocols

Cisco has supported two different trunking protocols over the years: Inter-Switch Link (ISL) and IEEE 802.1Q. Cisco created the ISL long before 802.1Q, in part because the IEEE had not yet defined a VLAN trunking standard. Years later, the IEEE completed work on the 802.1Q standard, which defines a different way to do trunking. Today, 802.1Q has become the more popular trunking protocol, with Cisco not even supporting ISL in some of its newer models of LAN switches, including the 2960 switches used in the examples in this book.

While both ISL and 802.1Q tag each frame with the VLAN ID, the details differ. 802.1Q inserts an extra 4-byte 802.1Q VLAN header into the original frame's Ethernet header, as shown at the top of Figure 9-6. As for the fields in the 802.1Q header, only the 12-bit VLAN ID field inside the 802.1Q header matters for topics discussed in this book. This 12-bit field supports a theoretical maximum of 2^{12} (4096) VLANs, while in practice, it supports a maximum of 4094. (Both 802.1Q and ISL use 12 bits to tag the VLAN ID, with two reserved values [0 and 4095].)

Key Topic

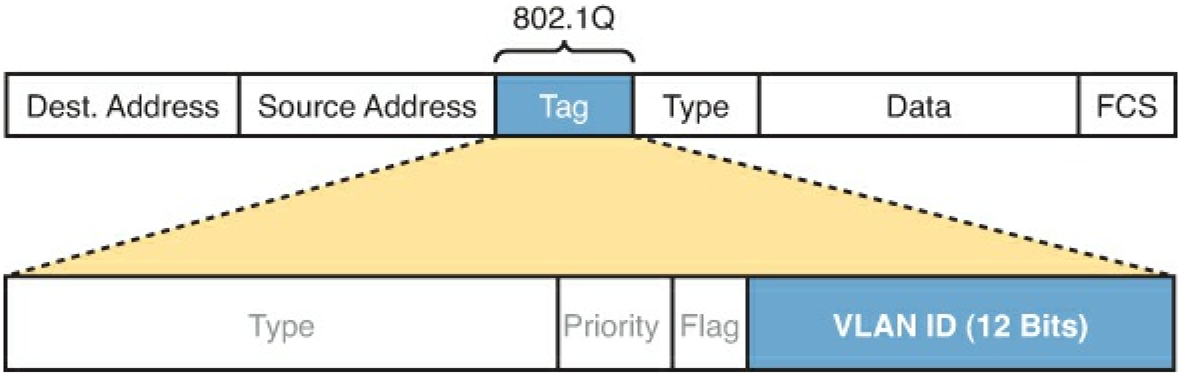


Figure 9-6. 802.1Q Trunking

Cisco switches break the range of VLAN IDs (1–4094) into two ranges: the normal range and the extended range. All switches can use normal-range VLANs with values from 1 to 1005. Only some switches can use extended-range VLANs with VLAN IDs from 1005 to 4094. The rules for which switches can use extended-range VLANs depend on the configuration of the VLAN Trunking Protocol (VTP), which is discussed briefly in the section "VLAN Trunking Configuration," later in this chapter.

802.1Q also defines one special VLAN ID on each trunk as the *native VLAN* (defaulting to use VLAN 1). By definition, 802.1Q simply does not add an 802.1Q header to frames in the native VLAN. When the switch on the other side of the trunk receives a frame that does not have an 802.1Q header, the receiving switch knows that the frame is part of the native VLAN. Note that because of this behavior, both switches must agree on which VLAN is the native VLAN.

The 802.1Q native VLAN provides some interesting functions, mainly to support connections to devices that do not understand trunking. For example, a Cisco switch could be cabled to a switch that does not understand 802.1Q trunking. The Cisco switch could send frames in the native VLAN—meaning that the frame has no trunking header—so that the other switch would understand the frame. The native VLAN concept gives switches the capability of at least passing traffic in one VLAN (the native VLAN), which can allow some basic functions, like reachability to telnet into a switch.

Forwarding Data Between VLANs

If you create a campus LAN that contains many VLANs, you typically still need all devices to be able to send data to all other devices. This next topic discusses some concepts about how to route data between those VLANs.

First, it helps to know a few terms about come categories of LAN switches. All the Ethernet switch functions described in this book so far use the details and logic defined by OSI Layer 2 protocols. For example, Chapter 6, "Building Ethernet LANs with Switches," discussed how LAN switches receive Ethernet frames (a Layer 2 concept), look at the destination Ethernet MAC address (a Layer 2 address), and forward the Ethernet frame out some other interface. This chapter has already discussed the concept of VLANs as broadcast domains, which is yet another Layer 2 concept.

While some LAN switches work just as described so far in this book, some LAN switches have even more functions. LAN switches that forward data based on Layer 2 logic, as discussed so far in this book, often go by the name *Layer 2 switch*. However, some other switches can do some functions like a router, using additional logic defined by Layer 3 protocols. These switches go by the name *multilayer switch*, or *Layer 3 switch*. This section first discusses how to forward data between VLANs when using Layer 2 switches and ends with a brief discussion of how to use Layer 3 switches.

Routing Packets Between VLANs with a Router

When including VLANs in a campus LAN design, the devices in a VLAN need to be in the same subnet. Following the same design logic, devices in different VLANs need to be in different subnets. For example, in Figure 9-7, the two PCs on the left sit in VLAN 10, in subnet 10. The two PCs on the right sit in a different VLAN (20), with a different subnet (20).

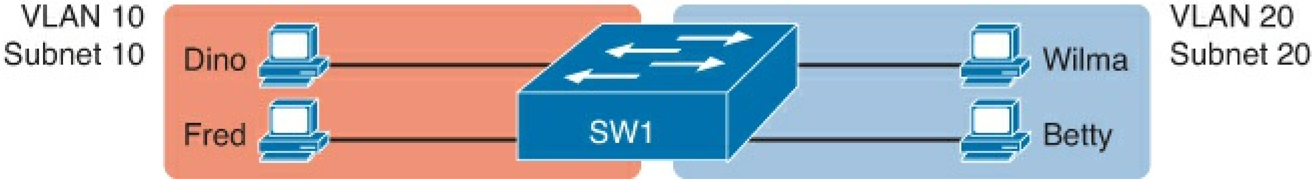


Figure 9-7. Routing Between VLANs on Two Physically Separated Switches

Note

The figure refers to subnets somewhat generally, like "subnet 10," just so the subnet numbers do not distract. Also, note that the subnet numbers do not have to be the same number as the VLAN numbers.

Layer 2 switches will not forward data between two VLANs. In fact, one goal of VLANs is to separate traffic in one VLAN from another, preventing frames in one VLAN from leaking over to other VLANs. For example, when Dino (in VLAN 10) sends any Ethernet frame, if SW1 is a Layer 2 switch, that switch will not forward the frame to the PCs on the right in VLAN 20.

The network as a whole needs to support traffic flowing into and out of each VLAN, even though the Layer 2 switch does not forward frames outside a VLAN. The job of forwarding data into and out of a VLAN falls to routers. Instead of switching Layer 2 Ethernet frames between the two VLANs, the network must route Layer 3 packets between the two subnets.

That previous paragraph has some very specific wording related to Layers 2 and 3, so take a moment to reread and reconsider it for a moment. The Layer 2 logic does not let the Layer 2 switch forward the Layer 2 PDU (L2PDU), the Ethernet frame, between VLANs. However, routers can route Layer 3 PDUs (L3PDU) (packets) between subnets as their normal job in life.

For example, Figure 9-8 shows a router that can route packets between subnets 10 and 20. The figure shows the same Layer 2 switch as shown in Figure 9-7, with the same PCs and with the same VLANs and subnets. Now Router R1 has one LAN physical interface connected to the switch and assigned to VLAN 10, and a second physical interface connected to the switch and assigned to VLAN 20. With an interface connected to each subnet, the Layer 2 switch can keep doing its job—forwarding frames inside a VLAN, while the router can do its job—routing IP packets between the subnets.

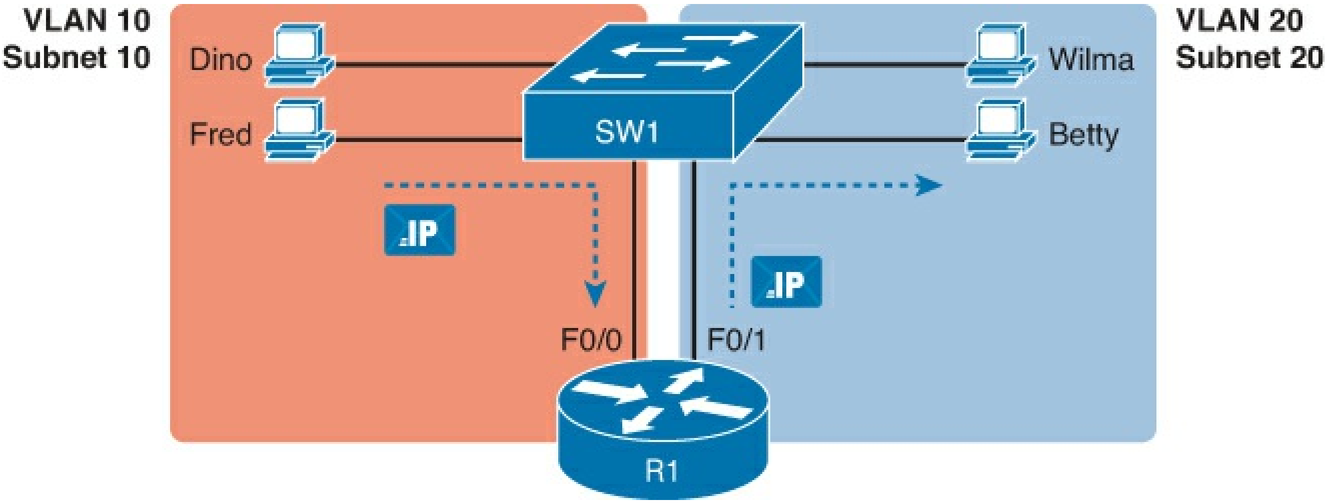


Figure 9-8. Routing Between Two VLANs on Two Physical Interfaces

The figure shows an IP packet being routed from Fred, which sits in one VLAN/subnet, to Betty, which sits in the other. The Layer 2 switch forwards two different Layer 2 Ethernet frames: one in VLAN 10, from Fred to R1's F0/0 interface, and the other in VLAN 20, from R1's F0/1 interface to Betty. From a Layer 3 perspective, Fred sends the IP packet to its default router (R1), and R1 routes the packet out another interface (F0/1) into another subnet where Betty resides.

While the design shown in Figure 9-8 works, it uses too many physical interfaces, one per VLAN. A much less expensive (and much preferred) option uses a VLAN trunk between the switch and router, requiring only one physical link between the router and switch, while supporting all VLANs. Trunking can work between any two devices that choose to support it: between two switches, between a router and a switch, or even between server hardware and a switch.

Figure 9-9 shows the same design idea as Figure 9-8, with the same packet being sent from Fred to Betty, except now R1 uses VLAN trunking instead of a separate link for each VLAN.

Key Topic

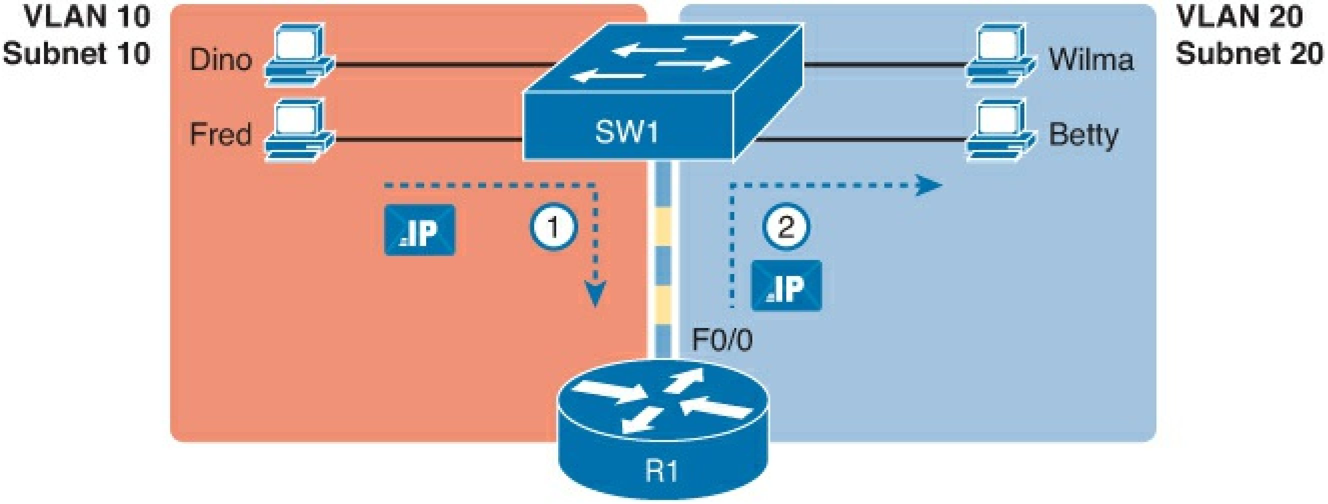


Figure 9-9. Routing Between Two VLANs Using a Trunk on the Router

> **Note**
>
> Because the router has a single physical link connected to the LAN switch, this design is sometimes called a router-on-a-stick.

As a brief aside about terminology, many people describe the concept in Figures 9-8 and 9-9 as "routing packets between VLANs." You can use that phrase, and people know what you mean. However, for exam preparation purposes, note that this phrase is not literally true, because it refers to routing packets (a Layer 3 concept) and VLANs (a Layer 2 concept). It just takes fewer words to say something like "routing between VLANs" rather than the literally true but long "routing Layer 3 packets between Layer 3 subnets, with those subnets each mapping to a different Layer 2 VLAN."

Routing Packets with a Layer 3 Switch

Routing packets using a physical router, even with the VLAN trunk in the router-on-a-stick model shown in Figure 9-9, still has one significant problem: performance. The physical link puts an upper limit on how many bits can be routed, and less expensive routers tend to be less powerful, and might not be able to route a large enough number of packets per second (pps) to keep up with the traffic volumes.

The ultimate solution moves the routing functions inside the LAN switch hardware. Vendors long ago started combining the hardware and software features of their Layer 2 LAN switches, plus their Layer 3 routers, creating products called *Layer 3 switches* (also known as *multilayer switches*). Layer 3 switches can be configured to act only as a Layer 2 switch, or they can be configured to do both Layer 2 switching as well as Layer 3 routing.

Today, many medium-to large-sized enterprise campus LANs use Layer 3 switches to route packets between subnets (VLANs) in a campus.

In concept, a Layer 3 switch works a lot like the original two devices on which the Layer 3 switch is based: a Layer 2 LAN switch and a Layer 3 router. In fact, if you take the concepts and packet flow shown in Figure 9-8, with a separate Layer 2 switch and Layer 3 router, and then image all those features happening inside one device, you have the general idea of what a Layer 3 switch does. Figure 9-10 shows that exact concept, repeating many details of Figure 9-8, but with an overlay that shows the one Layer 3 switch doing the Layer 2 switch functions and the separate Layer 3 routing function.

Key Topic

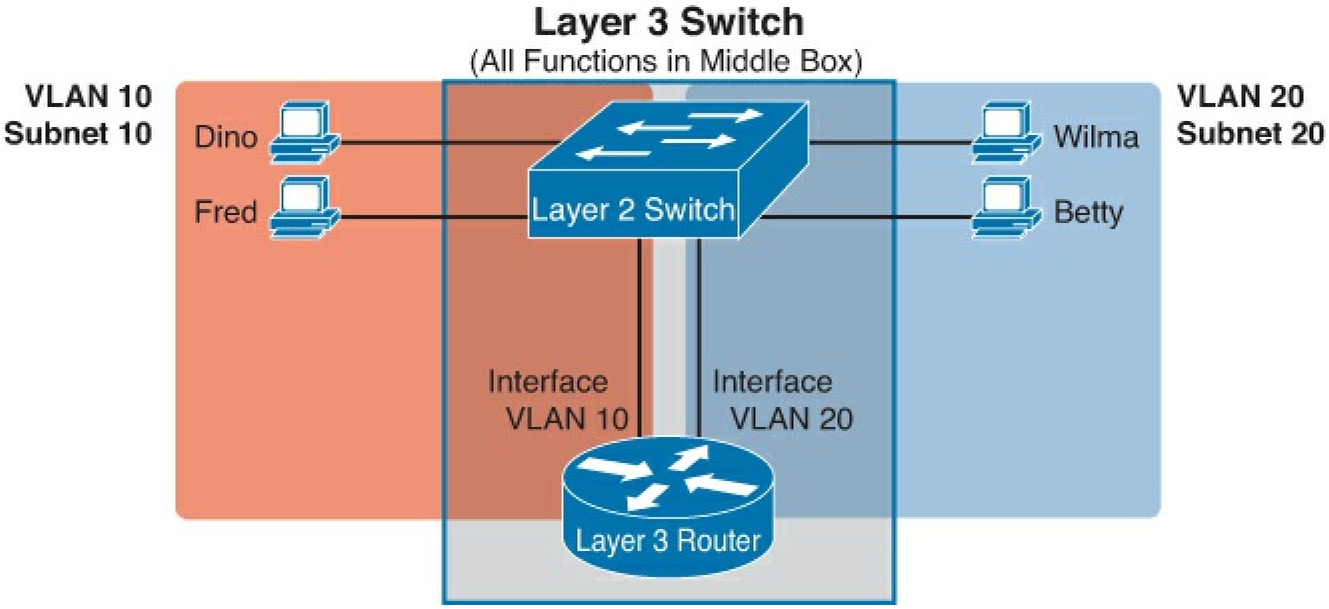


Figure 9-10. Multilayer Switch: Layer 2 Switching with Layer 3 Routing in One Device

This chapter introduces the core concepts of routing IP packets between VLANs (or more accurately, between the subnets on the VLANs). Chapter 16, "Configuring IPv4 Addresses and Routes," shows how to configure designs that use an external router with router-on-a-stick. This chapter now turns its attention to configuration and verification tasks for VLANs and VLAN trunks.

VLAN and VLAN Trunking Configuration and Verification

Cisco switches do not require any configuration to work. You can purchase Cisco switches, install devices with the correct cabling, turn on the switches, and they work. You would never need to configure the switch, and it would work fine, even if you interconnected switches, until you needed more than one VLAN. But if you want to use VLANs—and most every enterprise network does—you need to add some configuration.

This chapter separates the VLAN configuration details into two major sections. The first looks at how to configure access interfaces, which switch interfaces that do not use VLAN trunking. The second part shows how to configure interfaces that do use VLAN trunking.

Creating VLANs and Assigning Access VLANs to an Interface

This section shows how to create a VLAN, give the VLAN a name, and assign interfaces to a VLAN. To focus on these basic details, this section shows examples using a single switch, so VLAN trunking is not needed.

For a Cisco switch to forward frames in a particular VLAN, the switch must be configured to believe that the VLAN exists. Additionally, the switch must have nontrunking interfaces (called *access interfaces*) assigned to the VLAN, and/or trunks that support the VLAN. The configuration steps for access interfaces are as follows, with the trunk configuration shown later in the section "VLAN Trunking Configuration":

Key Topic

Step 1. To configure a new VLAN, follow these steps:

- **A.** From configuration mode, use the **vlan** *vlan-id* global configuration command to create the VLAN and to move the user into VLAN configuration mode.
- **B.** (Optional) Use the **name** *name* VLAN subcommand to list a name for the VLAN. If not configured, the VLAN name is VLAN*ZZZZ*, where *ZZZZ* is the 4-digit decimal VLAN ID.

Step 2. For each access interface (each interface that does not trunk, but instead belongs to a single VLAN), follow these steps:

- **A.** Use the **interface** command to move into interface configuration mode for each desired interface.
- **B.** Use the **switchport access vlan** *id-number* interface subcommand to specify the VLAN number associated with that interface.
- **C.** (Optional) To disable trunking on that same interface, so that the interface does not negotiate to become a trunk, use the **switchport mode access** interface subcommand.

While the list might look a little daunting, the process on a single switch is actually pretty simple. For example, if you want to put the switch's ports in three VLANs—11, 12, and 13—you just add three **vlan** commands: **vlan 11**, **vlan 12**, and **vlan 13**. Then, for each interface, add a **switchport access vlan 11** (or **12** or **13**) command to assign that interface to the proper VLAN.

VLAN Configuration Example 1: Full VLAN Configuration

Example 9-1 shows the configuration process of adding a new VLAN and assigning access interfaces to that VLAN. Figure 9-11 shows the network used in the example, with one LAN switch (SW1) and two hosts in each of three VLANs (1, 2, and 3). The example shows the details of the two-step process for VLAN 2 and the interfaces in VLAN 2, with the configuration of VLAN 3 deferred until the next example.

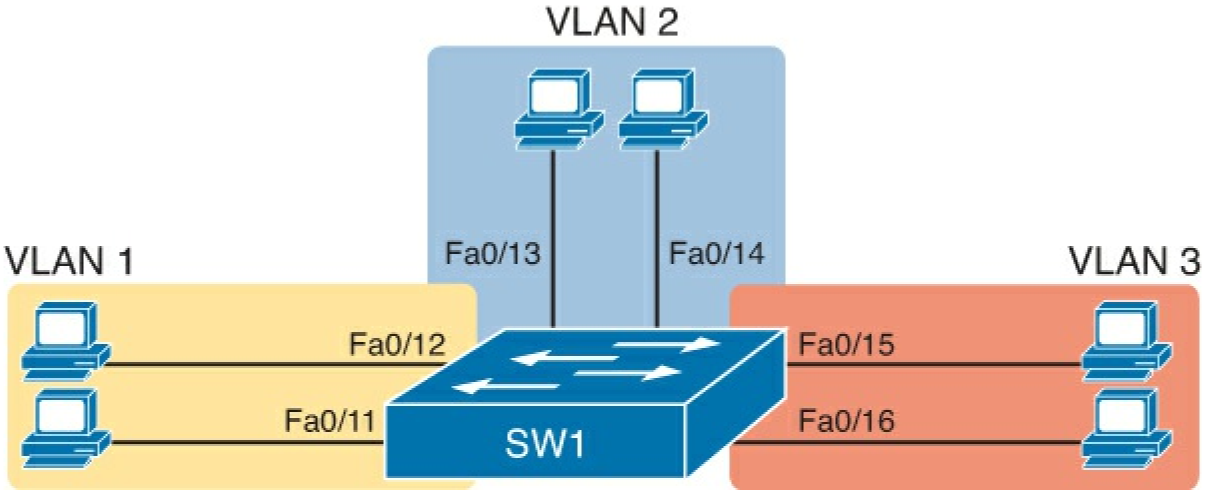


Figure 9-11. Network with One Switch and Three VLANs

Example 9-1. Configuring VLANs and Assigning VLANs to Interfaces

Click here to view code image

```
SW1# show vlan brief
VLAN Name Status Ports
---- -------------------------------- --------- -------------------------------
1 default active Fa0/1, Fa0/2, Fa0/3, Fa0/4
Fa0/5, Fa0/6, Fa0/7, Fa0/8
Fa0/9, Fa0/10, Fa0/11, Fa0/12
Fa0/13, Fa0/14, Fa0/15, Fa0/16
Fa0/17, Fa0/18, Fa0/19, Fa0/20
Fa0/21, Fa0/22, Fa0/23, Fa0/24
Gi0/1, Gi0/2
1002 fddi-default act/unsup
1003 token-ring-default act/unsup
1004 fddinet-default act/unsup
1005 trnet-default act/unsup
! Above, VLANs 2 and 3 do not yet exist. Below, VLAN 2 is added, with name Freds-vlan,
! with two interfaces assigned to VLAN 2.

SW1# configure terminal
```

```
Enter configuration commands, one per line. End with CNTL/Z.
SW1(config)# vlan 2
SW1(config-vlan)# name Freds-vlan
SW1(config-vlan)# exit
SW1(config)# interface range fastethernet 0/13 - 14
SW1(config-if)# switchport access vlan 2
SW1(config-if)# end

! Below, the show running-config command lists the interface subcommands on
! interfaces Fa0/13 and Fa0/14.
SW1# show running-config
! Many lines omitted for brevity
! Early in the output:
vlan 2
name Freds-vlan
!
! more lines omitted for brevity
interface FastEthernet0/13
switchport access vlan 2
switchport mode access
!
interface FastEthernet0/14
switchport access vlan 2
switchport mode access
!

SW1# show vlan brief

VLAN Name Status Ports
---- -------------------------------- --------- -------------------------------
1 default active Fa0/1, Fa0/2, Fa0/3, Fa0/4
Fa0/5, Fa0/6, Fa0/7, Fa0/8
Fa0/9, Fa0/10, Fa0/11, Fa0/12
Fa0/15, Fa0/16, Fa0/17, Fa0/18
Fa0/19, Fa0/20, Fa0/21, Fa0/22
Fa0/23, Fa0/24, Gi0/1, Gi0/2
2 Freds-vlan active Fa0/13, Fa0/14
1002 fddi-default act/unsup
1003 token-ring-default act/unsup
1004 fddinet-default act/unsup
1005 trnet-default act/unsup

SW1# show vlan id 2
VLAN Name Status Ports
---- -------------------------------- --------- -------------------------------
2 Freds-vlan active Fa0/13, Fa0/14

VLAN Type SAID MTU Parent RingNo BridgeNo Stp BrdgMode Trans1 Trans2
---- ----- ---------- ----- ------ ------ -------- ---- -------- ------ ------
2 enet 100010 1500 - - - - - 0 0

Remote SPAN VLAN
----------------
Disabled

Primary Secondary Type Ports
------- --------- ----------------- ------------------------------------------
```

The example begins with the **show vlan brief** command, confirming the default settings of five nondeletable VLANs, with all interfaces assigned to VLAN 1. (VLAN 1 cannot be deleted, but can be used. VLANs 1002–1005 cannot be deleted and cannot be used as access VLANs today.) In particular, note that this 2960 switch has 24 Fast Ethernet ports (Fa0/1–Fa0/24) and two Gigabit Ethernet ports (Gi0/1 and Gi0/2), all of which are listed as being in VLAN 1 per that first command's output.

Next, the example shows the process of creating VLAN 2 and assigning interfaces Fa0/13 and Fa0/14 to VLAN 2. Note in particular that the example uses the **interface range** command, which causes the **switchport access vlan 2** interface subcommand to be applied to both interfaces in the range, as confirmed in the **show running-config** command output at the end of the example.

After the configuration has been added, to list the new VLAN, the example repeats the **show vlan brief** command. Note that this command lists VLAN 2, name Freds-vlan, and the interfaces assigned to that VLAN (Fa0/13 and Fa0/14).

The example surrounding Figure 9-11 uses six switch ports, all of which need to operate as access ports. That is, each port should not use trunking, but instead should be assigned to a single VLAN, as assigned by the **switchport access vlan** *vlan-id* command. However, as configured in Example 9-1, these interfaces could negotiate to later become trunk ports, because the switch defaults to allow the port to negotiate trunking and decide whether to act as an access interface or as a trunk interface.

For ports that should always act as access ports, add the optional interface subcommand **switchport mode access**. This command tells the switch to only allow the interface to be an access interface. The upcoming section "VLAN Trunking Configuration" discusses more details about the commands that allow a port to negotiate whether it should use trunking.

VLAN Configuration Example 2: Shorter VLAN Configuration

Example 9-1 shows several of the optional configuration commands, with a side effect of being a bit longer than is required. Example 9-2 shows a much briefer alternative configuration, picking up the story where Example 9-1 ended and showing the addition of VLAN 3 (as seen in Figure 9-11). Note that SW1 does not know about VLAN 3 at the beginning of this example.

Example 9-2. Shorter VLAN Configuration Example (VLAN 3)

Click here to view code image

```
SW1# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
SW1(config)# interface range Fastethernet 0/15 - 16
SW1(config-if-range)# switchport access vlan 3
% Access VLAN does not exist. Creating vlan 3
SW1(config-if-range)# ^Z

SW1# show vlan brief

VLAN Name Status Ports
---- -------------------------------- --------- -------------------------------
1 default active Fa0/1, Fa0/2, Fa0/3, Fa0/4
Fa0/5, Fa0/6, Fa0/7, Fa0/8
Fa0/9, Fa0/10, Fa0/11, Fa0/12
Fa0/17, Fa0/18, Fa0/19, Fa0/20
Fa0/21, Fa0/22, Fa0/23, Fa0/24
Gi0/1, Gi0/2
2 Freds-vlan active Fa0/13, Fa0/14
3 VLAN0003 active Fa0/15, Fa0/16
1002 fddi-default act/unsup
1003 token-ring-default act/unsup
1004 fddinet-default act/unsup
1005 trnet-default act/unsup
```

Example 9-2 shows how a switch can dynamically create a VLAN—the equivalent of the **vlan** *vlan-id* global config command—when the **switchport access vlan** interface subcommand refers to a currently unconfigured VLAN. This example begins with SW1 not knowing about VLAN 3. When the **switchport access vlan 3** interface subcommand was used, the switch realized that VLAN 3 did not exist, and as noted in the shaded message in the example, the switch created VLAN 3, using a default name (VLAN0003). No other steps are required to create the VLAN. At the end of the process, VLAN 3 exists in the switch, and interfaces Fa0/15 and Fa0/16 are in VLAN 3, as noted in the shaded part of the **show vlan brief** command output.

VLAN Trunking Protocol (VTP)

Before showing more configuration examples, you also need to know something about an older Cisco protocol and tool called the VLAN Trunking Protocol (VTP). VTP is a Cisco-proprietary tool on Cisco switches that advertises each VLAN configured in one switch (with the **vlan** *number* command) so that all the other switches in the campus learn about that VLAN. However, for various reasons, many enterprises choose not to use VTP.

This book does not discuss VTP as an end to itself. However, VTP has some small impact on how every Cisco Catalyst switch works, even if you do not try and use VTP. This brief section introduces enough details of VTP so that you can see these small differences in VTP that cannot be avoided.

Each switch can use one of three VTP modes: server, client, or transparent. Switches use either VTP server or client mode when the switch wants to use VTP for its intended purpose of dynamically advertising VLAN configuration information. However, with many Cisco switches and IOS versions, VTP cannot be completely disabled on a Cisco switch; instead, the switch disables VTP by using VTP transparent mode.

This book attempts to ignore VTP as much as is possible. To that end, all examples in this book use switches that have either been set to use VTP transparent mode (with the **vtp mode transparent** global command) or to disable it (with the **vtp mode** off global command). Both options allow the administrator to configure both standard-and extended-range VLANs, and the switch lists the **vlan** commands in the running config file.

Finally, on a practical note, if you happen to do lab exercises with real switches or with simulators, and you see unusual results with VLANs, check the VTP status with the **show vtp status** command. If your switch uses VTP server or client mode, you will find

- The server switches can configure VLANs in the standard range only (1–1005).
- The client switches cannot configure VLANs.
- The **show running-config** command does not list any **vlan** commands.

If possible, switch to VTP transparent mode and ignore VTP for your switch configuration practice for the CCENT and CCNA exam.

> **Note**
>
> If you experiment with VTP settings on a real lab switch, be very careful. If that switch connects to other switches, which in turn connect to switches used in the production LAN, it is possible to cause problems by overwriting the VLAN configuration in other switches. Be careful and never experiment with VTP settings on a switch unless it, and the other switches connected to it, have absolutely no physical links connected to the production LAN.

VLAN Trunking Configuration

Trunking configuration between two Cisco switches can be very simple if you just statically configure trunking. For example, if two Cisco 2960 switches connect to each other, they support only 802.1Q and not ISL. You could literally add one interface subcommand for the switch interface on each side of the link (**switchport mode trunk**), and you would create a VLAN trunk that supported all the VLANs known to each switch.

However, trunking configuration on Cisco switches includes many more options, including several options for dynamically negotiating various trunking settings. The configuration can either predefine different settings or tell the switch to negotiate the settings, as follows:

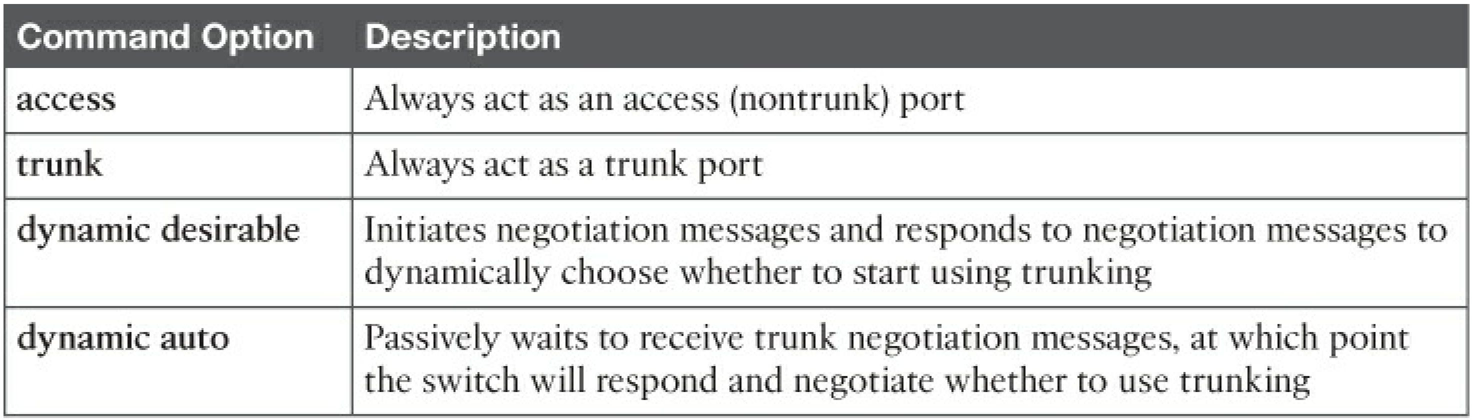
- The type of trunking: IEEE 802.1Q, ISL, or negotiate which one to use
- The *administrative mode*: Whether to always trunk, always not trunk, or negotiate

First, consider the type of trunking. Cisco switches that support ISL and 802.1Q can negotiate which type to use, using the Dynamic Trunking Protocol (DTP). If both switches support both protocols, they use ISL; otherwise, they use the protocol that both support. Today, many Cisco switches do not support the older ISL trunking protocol. Switches that support both types of trunking use the **switchport trunk encapsulation** {**dot1q** | **isl** | **negotiate**} interface subcommand to either configure the type or allow DTP to negotiate the type.

DTP can also negotiate whether the two devices on the link agree to trunk at all, as guided by the local switch port's administrative mode. The administrative mode refers to the configuration setting for whether trunking should be used. Each interface also has an *operational* mode, which refers to what is currently happening on the interface, and might have been chosen by DTP's negotiation with the other device. Cisco switches use the **switchport mode** interface subcommand to define the administrative trunking mode, as listed in Table 9-2.

Key Topic

Table 9-2. Trunking Administrative Mode Options with the switchport mode **Command**



Command Option	Description
access	Always act as an access (nontrunk) port
trunk	Always act as a trunk port
dynamic desirable	Initiates negotiation messages and responds to negotiation messages to dynamically choose whether to start using trunking
dynamic auto	Passively waits to receive trunk negotiation messages, at which point the switch will respond and negotiate whether to use trunking

For example, consider the two switches shown in Figure 9-12. This figure shows an expansion of the network of Figure 9-11, with a trunk to a new switch (SW2) and with parts of VLANs 1 and 3 on portsattached to SW2. The two switches use a Gigabit Ethernet link for the trunk. In this case, the trunk does not dynamically form by default, because both (2960) switches default to an administrative mode of *dynamic auto*, meaning that neither switch initiates the trunk negotiation process. By changing one switch to use *dynamic desirable* mode, which does initiate the negotiation, the switches negotiate to use trunking, specifically 802.1Q because the 2960s support only 802.1Q.

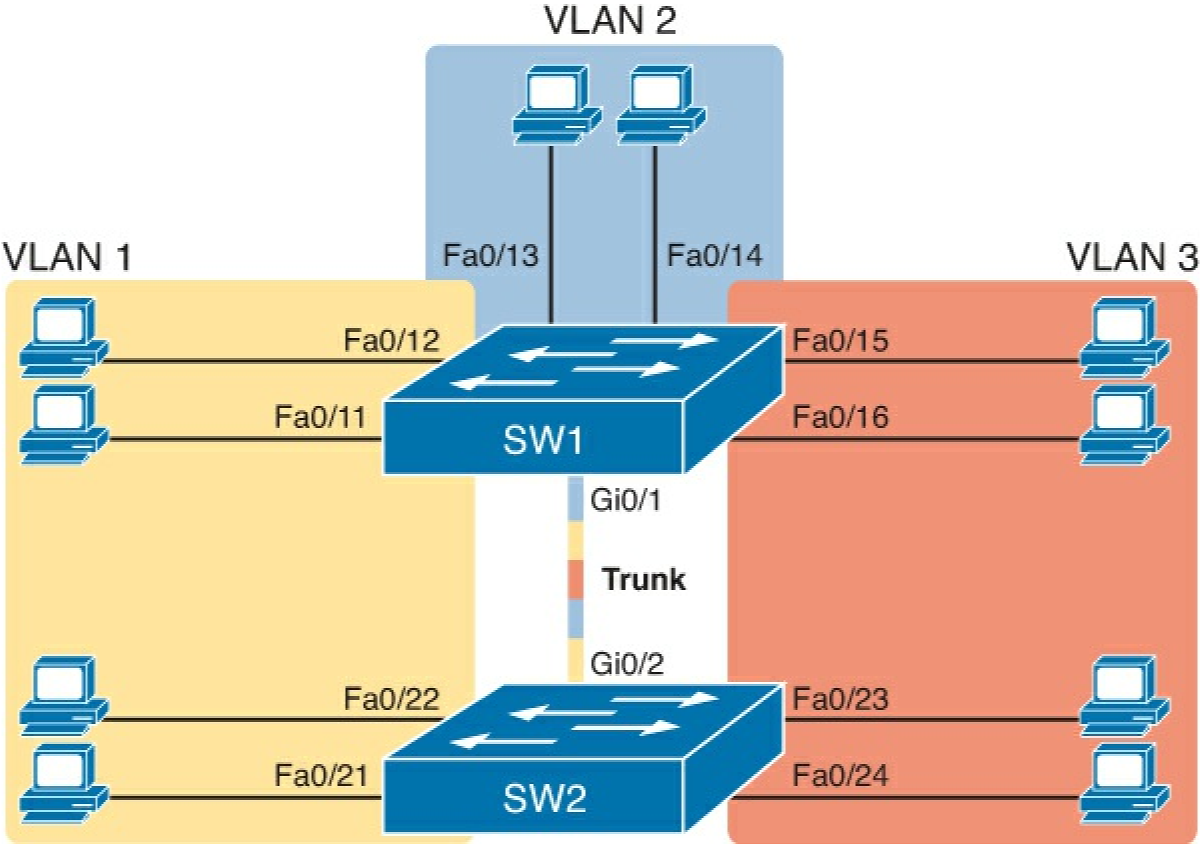


Figure 9-12. Network with Two Switches and Three VLANs

Example 9-3 begins by showing the two switches in Figure 9-12 with the default configuration so that the two switches do not trunk.

Example 9-3. Initial (Default) State: Not Trunking Between SW1 and SW2

Click here to view code image

```
SW1# show interfaces gigabit 0/1 switchport
Name: Gi0/1
Switchport: Enabled
Administrative Mode: dynamic auto
Operational Mode: static access
Administrative Trunking Encapsulation: dot1q
Operational Trunking Encapsulation: native
Negotiation of Trunking: On
Access Mode VLAN: 1 (default)
Trunking Native Mode VLAN: 1 (default)
Administrative Native VLAN tagging: enabled
Voice VLAN: none
Access Mode VLAN: 1 (default)
Trunking Native Mode VLAN: 1 (default)
Administrative Native VLAN tagging: enabled
Voice VLAN: none
Administrative private-vlan host-association: none
Administrative private-vlan mapping: none
Administrative private-vlan trunk native VLAN: none
Administrative private-vlan trunk Native VLAN tagging: enabled
Administrative private-vlan trunk encapsulation: dot1q
Administrative private-vlan trunk normal VLANs: none
Administrative private-vlan trunk private VLANs: none
Operational private-vlan: none
Trunking VLANs Enabled: ALL
Pruning VLANs Enabled: 2-1001
Capture Mode Disabled
Capture VLANs Allowed: ALL

Protected: false
```

```
Unknown unicast blocked: disabled
Unknown multicast blocked: disabled
Appliance trust: none

! Note that the next command results in a single empty line of output.
SW1# show interfaces trunk
SW1#
```

First, focus on the highlighted items from the output of the **show interfaces switchport** commandat the beginning of Example 9-3. The output lists the default administrative mode setting of dynamic auto. Because SW2 also defaults to dynamic auto, the command lists SW1's operational status as access, meaning that it is not trunking. ("Dynamic auto" tells both switches to sit there and wait on the other switch to start the negotiations.) The third shaded line points out the only supported type of trunking (802.1Q) on this 2960 switch. (On a switch that supports both ISL and 802.1Q, this value would by default list "negotiate," to mean that the type of encapsulation is negotiated.) Finally, the operational trunking type is listed as "native," which is a reference to the 802.1Q native VLAN.

The end of the example shows the output of the **show interfaces trunk** command, but with no output. This command lists information about all interfaces that currently operationally trunk; that is, it list interfaces that currently use VLAN trunking. With no interfaces listed, this command also confirms that the link between switches is not trunking.

Next, consider Example 9-4, which shows the new configuration that enables trunking. In this case, SW1 is configured with the **switchport mode dynamic desirable** command, which asks the switch to both negotiate as well as to begin the negotiation process, rather than waiting on the other device. As soon as the command is issued, log messages appear showing that the interface goes down and then back up again, which happens when the interface transitions from access mode to trunk mode.

Example 9-4. SW1 Changes from Dynamic Auto to Dynamic Desirable

Click here to view code image

```
SW1# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
SW1(config)# interface gigabit 0/1
SW1(config-if)# switchport mode dynamic desirable
SW1(config-if)# ^Z
SW1#
01:43:46: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet0/1, changed
state to down
01:43:49: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet0/1, changed
state to up
SW1# show interfaces gigabit 0/1 switchport
Name: Gi0/1
Switchport: Enabled
Administrative Mode: dynamic desirable
Operational Mode: trunk
Administrative Trunking Encapsulation: dot1q
Operational Trunking Encapsulation: dot1q
Negotiation of Trunking: On
Access Mode VLAN: 1 (default)
Trunking Native Mode VLAN: 1 (default)
! lines omitted for brevity

! The next command formerly listed a single empty line of output; now it lists
! information about the 1 operational trunk.
SW1# show interfaces trunk

Port Mode Encapsulation Status Native vlan
Gi0/1 desirable 802.1q trunking 1

Port Vlans allowed on trunk
Gi0/1 1-4094

Port Vlans allowed and active in management domain
Gi0/1 1-3

Port Vlans in spanning tree forwarding state and not pruned
Gi0/1 1-3

SW1# show vlan id 2
VLAN Name Status Ports
```

```
---- -------------------------------- --------- -------------------------------
2 Freds-vlan active Fa0/13, Fa0/14, G0/1

VLAN Type SAID MTU Parent RingNo BridgeNo Stp BrdgMode Trans1 Trans2
---- ----- ---------- ----- ------ ------ -------- ---- -------- ------ ------
2 enet 100010 1500 - - - - - 0 0

Remote SPAN VLAN
----------------
Disabled

Primary Secondary Type Ports
------- --------- ----------------- ------------------------------------------
```

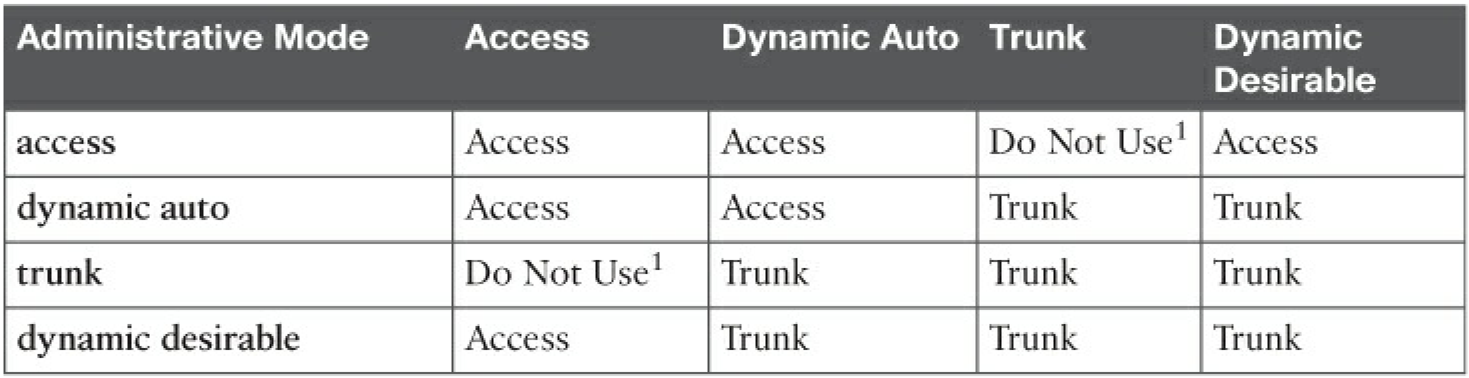
To verify that trunking is working now, the middle of Example 9-4 lists the **show interfaces switchport** command. Note that the command still lists the administrative settings, which denote the configured values along with the operational settings, which list what the switch is currently doing. In this case, SW1 now claims to be in an operational mode of *trunk*, with an operational trunking encapsulation of dot1Q.

The end of the example shows the output of the **show interfaces trunk** command, which now lists G0/1, confirming that G0/1 is now operationally trunking. The next section discusses the meaning of the output of this command.

For the exams, you should be ready to interpret the output of the **show interfaces switchport** command, realize the administrative mode implied by the output, and know whether the link should operationally trunk based on those settings. Table 9-3 lists the combinations of the trunking administrative modes and the expected operational mode (trunk or access) resulting from the configured settings. The table lists the administrative mode used on one end of the link on the left, and the administrative mode on the switch on the other end of the link across the top of the table.

Key Topic

Table 9-3. Expected Trunking Operational Mode Based on the Configured Administrative Modes



Administrative Mode	Access	Dynamic Auto	Trunk	Dynamic Desirable
access	Access	Access	Do Not Use[1]	Access
dynamic auto	Access	Access	Trunk	Trunk
trunk	Do Not Use[1]	Trunk	Trunk	Trunk
dynamic desirable	Access	Trunk	Trunk	Trunk

Finally, before leaving the discussion of configuring trunks, Cisco recommends disabling trunk negotiation on most ports for better security. The majority of switch ports on most switches will be used to connect to users. As a matter of habit, you can disable DTP negotiations altogether using the **switchport nonegotiate** interface subcommand.

Controlling Which VLANs Can Be Supported on a Trunk

The *allowed VLAN list* feature provides a mechanism for engineers to administratively disable a VLAN from a trunk. By default, switches include all possible VLANs (1–4094) in each trunk's allowed VLAN list. However, the engineer can then limit the VLANs allowed on the trunk by using the following interface subcommand:

```
switchport trunk allowed vlan {add | all | except | remove} vlan-list
```

This command provides a way to easily add and remove VLANs from the list. For example, the **add** option permits the switch to add VLANs to the existing allowed VLAN list, and the **remove** option permits the switch to remove VLANs from the existing list. The **all** option means all VLANs, so you can use it to reset the switch to its original default setting (permitting VLANs 1–4094 on the trunk). The **except** option is rather tricky: It adds all VLANs to the list that are not part of the command. For example, the **switchport trunk allowed vlan except 100-200** interface subcommand adds VLANs 1 through 99 and 201 through 4094 to the existing allowed VLAN list on that trunk.

In addition to the allowed VLAN list, a switch has other reasons to prevent a particular VLAN's traffic from crossing a trunk. All five reasons are summarized in the following list:

Key Topic

- A VLAN has been removed from the trunk's *allowed VLAN* list.
- A VLAN does not exist in the switch's configuration (as seen with the **show vlan** command).
- A VLAN does exist, but has been administratively disabled (**shutdown**).
- A VLAN has been automatically pruned by VTP.
- A VLAN's STP instance has placed the trunk interface into a blocking state.

> **Note**
>
> The last two reasons in the list are outside the scope of this book, but are mentioned here for completeness.

While this section has already discussed the first reason—the allowed VLAN list—next consider the next two reasons in the list. If a switch does not know that a VLAN exists—for example, if the switch does not have a **vlan** *vlan-id* command configured, as confirmed by the output of the **show vlan** command—the switch will not forward frames in that VLAN over any interface. Additionally, a VLAN can exist in a switch's configuration, but also be administratively shut down either by using the **shutdown vlan** *vlan-id* global configuration command, or using the **shutdown** command in VLAN configuration mode. When disabled, a switch will no longer forward frames in that VLAN, even over trunks. So, switches do not forward frames in nonexistent VLANs or a shutdown VLAN over any of the switch's trunks.

This book has a motive for listing the reasons for limiting VLANs on a trunk: The **show interfaces trunk** command lists VLAN ID ranges as well, based on these same reasons. This command includes a progression of three lists of the VLANs supported over a trunk. These three lists are as follows:

- VLANs allowed on the trunk, 1–4094 by default
- VLANs from the first group that are also configured and active (not shut down)
- VLANs from the second group that are not VTP pruned and not STP blocked

To get an idea of these three lists inside the output of the **show interfaces trunk** command, Example 9-5 shows how VLANs might be disallowed on a trunk for various reasons. The command output is taken from SW1 in Figure 9-12, after the completion of the configuration as shown in all the earlier examples in this chapter. In other words, VLANs 1 through 3 exist in SW1's configuration, and are not shut down. Trunking is operational between SW1 and SW2. Then, during the example, the following items are configured on SW1:

Step 1. VLAN 4 is configured.

Step 2. VLAN 2 is shut down.

Step 3. VLAN 3 is removed from the trunk's allowed VLAN list.

Example 9-5. Allowed VLAN List and the List of Active VLANs

Click here to view code image

```
! The three lists of VLANs in the next command list allowed VLANs (1-4094),
! Allowed and active VLANs (1-3), and allowed/active/not pruned/STP forwarding
! VLANs (1-3)
SW1# show interfaces trunk

Port Mode Encapsulation Status Native vlan
Gi0/1 desirable 802.1q trunking 1

Port Vlans allowed on trunk
Gi0/1 1-4094

Port Vlans allowed and active in management domain
Gi0/1 1-3

Port Vlans in spanning tree forwarding state and not pruned
Gi0/1 1-3

! Next, the switch is configured with new VLAN 4; VLAN 2 is shutdown;
! and VLAN 3 is removed from the allowed VLAN list on the trunk.
SW1# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
SW1(config)# vlan 4
SW1(config-vlan)# vlan 2
SW1(config-vlan)# shutdown
SW1(config-vlan)# interface gi0/1
```

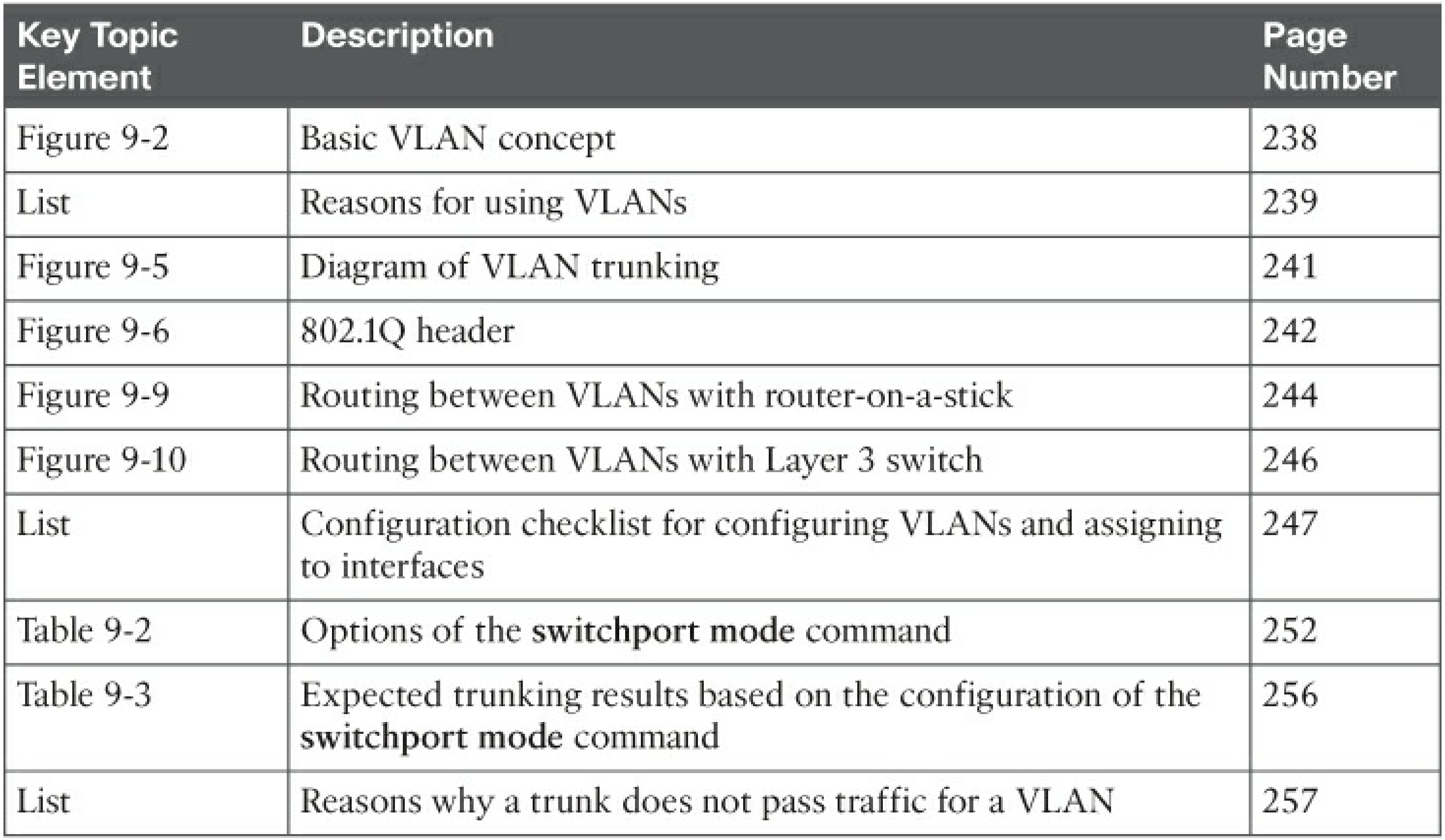
```
SW1(config-if)# switchport trunk allowed vlan remove 3
SW1(config-if)# ^Z

! The three lists of VLANs in the next command list allowed VLANs (1-2, 4-4094),
! allowed and active VLANs (1,4), and allowed/active/not pruned/STP forwarding
! VLANs (1,4)
SW1# show interfaces trunk

Port Mode Encapsulation Status Native vlan
Gi0/1 desirable 802.1q trunking 1

! VLAN 3 is omitted next, because it was removed from the allowed VLAN list.
Port Vlans allowed on trunk
Gi0/1 1-2,4-4094

! VLAN 2 is omitted below because it is shutdown. VLANs 5-4094 are omitted below
! because SW1 does not have them configured.
Port Vlans allowed and active in management domain
Gi0/1 1,4

Port Vlans in spanning tree forwarding state and not pruned
Gi0/1 1,4
```

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 9-4 lists these key topics and where each is discussed.

Table 9-4. Key Topics for Chapter 9



Key Topic Element	Description	Page Number
Figure 9-2	Basic VLAN concept	238
List	Reasons for using VLANs	239
Figure 9-5	Diagram of VLAN trunking	241
Figure 9-6	802.1Q header	242
Figure 9-9	Routing between VLANs with router-on-a-stick	244
Figure 9-10	Routing between VLANs with Layer 3 switch	246
List	Configuration checklist for configuring VLANs and assigning to interfaces	247
Table 9-2	Options of the **switchport mode** command	252
Table 9-3	Expected trunking results based on the configuration of the **switchport mode** command	256
List	Reasons why a trunk does not pass traffic for a VLAN	257

Complete the Tables and Lists from Memory

Print a copy of Appendix M, "Memory Tables," (found on the DVD) or at least the section for this chapter, and complete the tables and lists from memory. Appendix N, "Memory Tables Answer Key," also on the DVD, includes completed tables and lists to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

802.1Q
trunk
trunking administrative mode
trunking operational mode
VLAN
VTP
VTP transparent mode
Layer 3 switch
access interface
trunk interface

Command Reference to Check Your Memory

While you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To check and see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table with a piece of paper, read the descriptions in the right side, and see whether you remember the command.

Table 9-5. Chapter 9 Configuration Command Reference

Command	Description
vlan *vlan-id*	Global config command that both creates the VLAN and puts the CLI into VLAN configuration mode
name *vlan-name*	VLAN subcommand that names the VLAN
[no] shutdown	VLAN mode subcommand that enables (**no shutdown**) or disables (**shutdown**) the VLAN
[no] shutdown vlan *vlan-id*	Global config command that has the same effect as the **[no] shutdown** VLAN mode subcommands
vtp mode {**server** | **client** | **transparent** | **off**}	Global config command that defines the VTP mode
switchport mode {**access** | **dynamic** {**auto** | **desirable**} | **trunk**}	Interface subcommand that configures the trunking administrative mode on the interface
switchport trunk allowed vlan {**add** | **all** | **except** | **remove**} *vlan-list*	Interface subcommand that defines the list of allowed VLANs
switchport access vlan *vlan-id*	Interface subcommand that statically configures the interface into that one VLAN
switchport trunk encapsulation {**dot1q** | **isl** | **negotiate**}	Interface subcommand that defines which type of trunking to use, assuming that trunking is configured or negotiated
switchport trunk native vlan *vlan-id*	Interface subcommand that defines the native VLAN for a trunk port
switchport nonegotiate	Interface subcommand that disables the negotiation of VLAN trunking

Table 9-6. Chapter 9 EXEC Command Reference

Command	Description
show interfaces *interface-id* **switchport**	Lists information about any interface regarding administrative settings and operational state
show interfaces *interface-id* **trunk**	Lists information about all operational trunks (but no other interfaces), including the list of VLANs that can be forwarded over the trunk
show vlan [**brief** | **id** *vlan-id* / **name** *vlan-name* | **summary**]	Lists information about the VLAN
show vlan [*vlan*]	Displays VLAN information
show vtp status	Lists VTP configuration and status information

Chapter 10. Troubleshooting Ethernet LANs

This chapter covers the following exam topics:

- **LAN Switching Technologies**
  - Configure and verify trunking on Cisco switches
    - DTP
    - Autonegotiation
- **Network Device Security**
  - Configure and verify Switch Port Security features such as
    - Static / dynamic
    - Violation modes
      - Err disable
      - Shutdown
      - Protect restrict
- **Troubleshooting**
  - Troubleshoot and Resolve VLAN problems
    - identify that VLANs are configured
    - port membership correct
    - IP address configured
  - Troubleshoot and Resolve trunking problems on Cisco switches
    - correct trunk states
    - correct encapsulation configured
    - correct VLANs allowed
  - Troubleshoot and Resolve Layer 1 problems
    - Framing
    - CRC
    - Runts
    - Giants
    - Dropped packets
    - Late collision
    - Input / Output errors

This chapter focuses on the processes of verification and troubleshooting. *Verification* refers to the process of confirming whether a network is working as designed. *Troubleshooting* refers to the follow-on process that occurs when the network is not working as designed, by trying to determine the real reason why the network is not working correctly, so that it can be fixed.

Over the years, the CCENT and CCNA exams have been asking more and more verification and troubleshooting questions. Each of these questions requires you to apply networking knowledge to unique problems, rather than just being ready to answer questions about lists of facts that you've memorized.

To help you prepare to answer troubleshooting questions, this book, as well as the ICND2 book, devotes different book elements (both full chapters and sections of chapters) to troubleshooting. These book elements do not just list the configuration, and they do not just list example output from different **show** commands. Instead, these elements discuss how to use different commands to verify what should be happening, and if not, how to find the root cause of the problem.

This chapter discusses a wide number of topics, many of which have already been discussed in Chapters 6, 7, 8, and 9. First, this chapter begins with some perspectives on troubleshooting networking problems, because it is the first book element that focuses on troubleshooting. At that point, this chapter looks at four key technical topics that matter to verifying and troubleshooting Ethernet LANs, as follows:

- Analyzing LAN Topology Using CDP
- Analyzing Switch Interface Status
- Predicting Where Switches Will Forward Frames
- Analyzing VLANs and VLAN Trunks

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 10-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping

Foundation Topics Section	Questions
Perspectives on Network Verification and Troubleshooting	—
Analyzing LAN Topology Using CDP	1, 2
Analyzing Switch Interface Status	3–5
Predicting Where Switches Will Forward Frames	6, 7
Analyzing VLANs and VLAN Trunks	8

1. Imagine that a switch connects through an Ethernet cable to a router, and the router's host name is Hannah. Which of the following commands could tell you information about the IOS version on Hannah without establishing a Telnet connection to Hannah? (Choose two answers.)

   a. show neighbors Hannah

   b. show cdp

   c. show cdp neighbors

   d. show cdp neighbors Hannah

   e. show cdp entry Hannah

   f. show cdp neighbors detail

2. A switch is cabled to a router whose host name is Hannah. Which of the following CDP commands could identify Hannah's model of hardware? (Choose two answers.)

   a. show neighbors

   b. show neighbors Hannah

   c. show cdp

   d. show cdp interface

   e. show cdp neighbors

   f. show cdp entry Hannah

3. The output of the **show interfaces status** command on a 2960 switch shows interface Fa0/1 in a "disabled" state. Which of the following is true about interface Fa0/1? (Choose three answers.)

   a. The interface is configured with the **shutdown** command.

   b. The **show interfaces fa0/1** command will list the interface with two status codes of administratively down and line protocol down.

   c. The **show interfaces fa0/1** command will list the interface with two status codes of up and down.

   d. The interface cannot currently be used to forward frames.

   e. The interface can currently be used to forward frames.

4. Switch SW1 uses its Gigabit 0/1 interface to connect to switch SW2's Gigabit 0/2 interface. SW2's Gi0/2 interface is configured with the **speed 1000** and **duplex full** commands. SW1 uses all defaults for interface configuration commands on its Gi0/1 interface. Which of the following are true about the link after it comes up? (Choose two answers.)

   a. The link works at 1000 Mbps (1 Gbps).

   b. SW1 attempts to run at 10 Mbps because SW2 has effectively disabled IEEE standard autonegotiation.

   c. The link runs at 1 Gbps, but SW1 uses half-duplex and SW2 uses full-duplex.

   d. Both switches use full-duplex.

5. The following line of output was taken from a **show interfaces fa0/1** command:

```
Full-duplex, 100Mbps, media type is 10/100BaseTX
```

   Which of the following are true about the interface? (Choose two answers.)

   a. The speed was definitely configured with the **speed 100** interface subcommand.

   b. The speed might have been configured with the **speed 100** interface subcommand.

   c. The duplex was definitely configured with the **duplex full** interface subcommand.

   d. The duplex might have been configured with the **duplex full** interface subcommand.

6. Which of the following commands list the MAC address table entries for MAC addresses configured by port security? (Choose two answers.)

   a. show mac address-table dynamic

   b. show mac address-table

c. show mac address-table static

d. show mac address-table port-security

7. On a Cisco Catalyst switch, you issue a **show mac address-table** command. Which of the following answers list information you would likely see in most lines of output? (Choose two answers.)

   a. A MAC address

   b. An IP address

   c. A VLAN ID

   d. Type (broadcast, multicast, or unicast**)**

8. Layer 2 switches SW1 and SW2 connect through a link, with port G0/1 on SW1 and port G0/2 on SW2. The network engineer wants to use 802.1Q trunking on this link. The **show interfaces g0/1 switchport** command on SW1 shows the output listed here:

Click here to view code image

```
SW1# show interfaces gigabit0/1 switchport
Name: Gi0/1
Switchport: Enabled
Administrative Mode: trunk
Operational Mode: trunk
```

Which of the following must be true on switch SW2's G0/2 port?

a. The operational state per the **show interfaces switchport** command must be "trunk."

b. The administrative state per the **show interfaces switchport** command must be "trunk."

c. SW2 must use the **switchport mode trunk** configuration command on G0/2, or the link will not use trunking.

d. SW2 can use the **switchport mode dynamic auto** configuration command as one option to make the link use trunking.

Answers to the "Do I Know This Already?" quiz:

1 E and F 2 E and F 3 A, B, and D 4 A and D 5 B and D 6 B and C 7 A and C 8 D

Foundation Topics

Perspectives on Network Verification and Troubleshooting

> **Note**
>
> The information in this section is a means to help you learn troubleshooting skills. However, the specific processes and comments in this section, up to the next major heading ("Analyzing LAN Topology Using Cisco Discovery Protocol"), do not cover any specific exam objective for any of the CCENT or CCNA exams.

You need several skills to be ready to answer the more challenging questions on today's CCENT and CCNA exams. However, the required skills differ when comparing the different types of questions. This section starts with some perspectives on the various question types, followed by some general comments on troubleshooting.

First, as a reminder, the Introduction to this book briefly describes a couple of different types of exam questions mentioned in this chapter: Sim, Simlet, and multiple choice (MC).

Sim and Simlet questions use a simulator, where you can use the CLI of simulated routers and switches. Sim questions require you to find a configuration problem and solve the problem by fixing or completing the configuration. Simlet questions require you to verify the current operation of the network and then answer MC questions about the current operation. MC questions simply ask a question, with multiple answers (choices) for the correct answer.

> **Note**
>
> Refer to www.cisco.com/web/learning/wwtraining/certprog/training/cert_exam_tutorial.html for a tutorial about the various types of CCENT and CCNA exam questions.

Preparing to Use an Organized Troubleshooting Process

On exam day, you have one goal: answer enough questions correctly to pass the exam. However, before the exam, you should use a thorough and organized thought process. You can learn a lot by thinking through the troubleshooting process as you prepare for the exam so that you can be better prepared to attack problems quickly on exam day.

To that end, this book includes many suggested troubleshooting processes. The troubleshooting processes are not ends unto themselves, so you do not need to memorize them for the exams. They are learning tools, with the ultimate goal being to help you correctly and quickly find the answers to the more challenging questions on the exams.

This section gives an overview of a general troubleshooting process. As you progress through this book, the process will be mentioned occasionally as it relates to other technology areas, such as IP routing. The three major steps in this book's organized troubleshooting process are as follows:

Step 1. **Analyzing/predicting normal operation:** Predict the details of what should happen if the network is working correctly, based on documentation, configuration, and **show** and **debug** command output.

Step 2. **Problem isolation:** Determine how far along the expected path the frame/packet goes before it cannot be forwarded any farther, again based on documentation, configuration, and **show** and **debug** command output.

Step 3. **Root cause analysis:** Identify the underlying causes of the problems identified in the preceding step—specifically, the causes that have a specific action with which the problem can be fixed.

Following this process requires a wide variety of learned skills. You need to remember the theory of how networks should work, as well as how to interpret the **show** command output that confirms how the devices are currently behaving. This process requires the use of testing tools, such as **ping** and **traceroute**, to isolate the problem. Finally, this approach requires the ability to think broadly about everything that could affect a single component.

For example, consider the following problem based on the network in Figure 10-1. PC1 and PC2 supposedly sit in the same VLAN (10). At one time, the **ping 10.1.1.2** command on PC1 worked; now it does not.

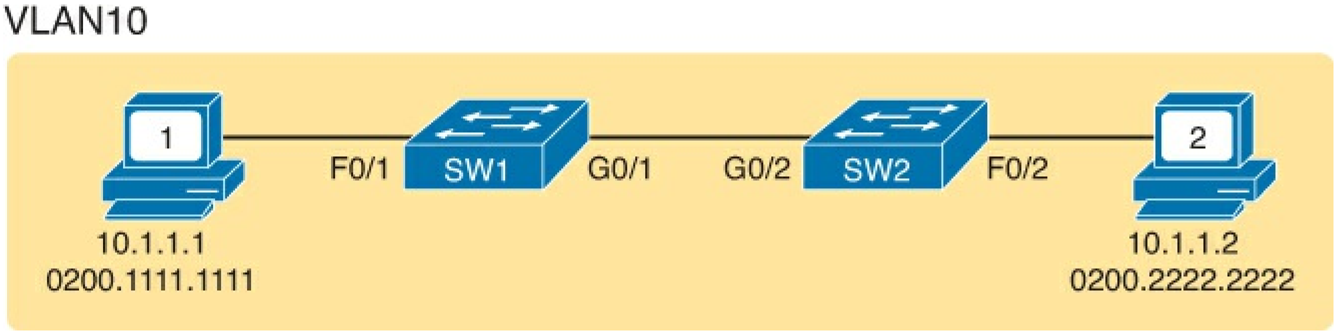


Figure 10-1. Example Network with a ping Problem

So, how do you attack this problem? If you doubt whether the figure is even correct, you could look at **show** command output to confirm the network topology. After it is confirmed, you could predict its normal working behavior based on your knowledge of LAN switching. As a result, you could predict where a frame sent by PC1 to PC2 should flow. To isolate the problem, you could look in the switch MAC tables to confirm the interfaces out which the frame should be forwarded, possibly then finding that the interface connected to PC2 has failed.

If you did conclude that an interface had failed, you still do not know the root cause: What caused the interface to fail? What could you do to fix that underlying problem? In that particular case, you would then need to broaden your thinking to any and all reasons why an interface might fail—from an unplugged cable, to electrical interference, to port security disabling the interface. **show** commands can either confirm that a specific root cause is the problem or at least give some hints as to the root cause.

The first example problem uses a simple LAN, with one subnet and no need for IP routing. However, many exam questions will include multiple IP subnets, with routers that must route IP packets between the hosts. In these cases, the troubleshooting process often begins with some analysis of how the Layer 3 routing process works when forwarding IP packets.

For example, the user of PC1 in Figure 10-2 can usually connect to the web server on the right by entering www.example.com in PC1's web browser. However, that web-browsing attempt fails right now. The user calls the help desk, and the problem is assigned to a network engineer to solve.

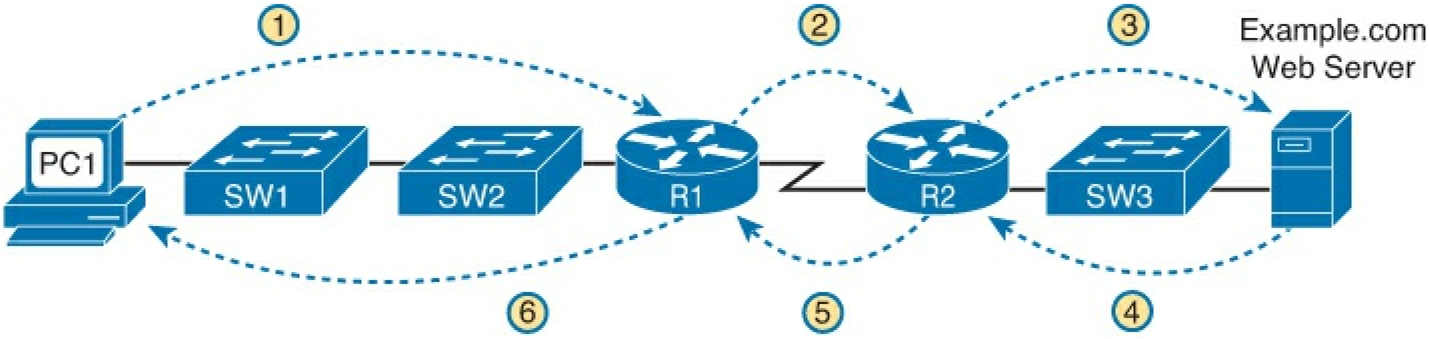


Figure 10-2. Layer 3 Problem Isolation

To begin the analysis, the network engineer can begin with the first tasks that would have to happen for a successful web-browsing session to occur. For example, the engineer would try to confirm that PC1 can resolve the host name (www.example.com) to the correct IP address used by the server on the right. At that point, the Layer 3 IP problem isolation process can proceed, to determine which of the six routing steps shown in the figure has failed. The routing steps shown in Figure 10-2 are as follows:

Step 1. PC1 sends the packet to its default gateway (R1) because the destination IP address (of the web server) is in a different subnet.

Step 2. R1 forwards the packet to R2 based on R1’s routing table.

Step 3. R2 forwards the packet to the web server based on R2’s routing table.

Step 4. The web server sends a packet back toward PC1 based on the web server’s default gateway setting (R2).

Step 5. R2 forwards the packet destined for PC1 by forwarding the packet to R1 according to R2’s routing table.

Step 6. R1 forwards the packet to PC1 based on R1’s routing table.

Many engineers break down network problems as in this list, analyzing the Layer 3 path through the network, hop by hop, in both directions. This process helps you take the first attempt at problem isolation. When the analysis shows which hop in the layer path fails, you can then look further at those details. And if in this case the Layer 3 problem isolation process discovers that Step 1, 3, 4, or 6 fails, the root cause might be related to Ethernet.

For example, imagine that the Layer 3 analysis determined that PC1 cannot even send a packet to its default gateway (R1), meaning that Step 1 in Figure 10-2 fails. To further isolate the problem and find the root causes, the engineer would need to determine the following:

- The MAC address of PC1 and of R1’s LAN interface
- The switch interfaces used on SW1 and SW2
- The interface status of each switch interface
- The VLANs that should be used
- The expected forwarding behavior of a frame sent by PC1 to R1 as the destination MAC address

By gathering and analyzing these facts, the engineer can most likely isolate the problem’s root cause and fix it.

Troubleshooting as Covered in This Book

In the current version of the ICND1 and ICND2 exams, Cisco spreads troubleshooting topics across both exams. However, in the current versions of the exams (100-101 ICND1 and 200-101 ICND2), more of the troubleshooting sits in the ICND2 exam, with less in the ICND1 exam. As a result, this book has one chapter devoted to troubleshooting (this chapter), with some other smaller troubleshooting topics spread throughout different chapters. The companion *Cisco CCNA Routing and Switching ICND2 200-101 Official Cert Guide* has many more troubleshooting elements by comparison.

The rest of this chapter examines troubleshooting related to Ethernet LANs, with four major topics. Of these, only the first topic, about the Cisco Discovery Protocol (CDP), presents completely new material. The other three topics discuss familiar topics, but with a troubleshooting approach. The topics include the following:

- **Cisco Discovery Protocol (CDP):** Used to confirm the documentation, and learn about the network topology, to predict normal operation of the network.
- **Examining interface status:** Interfaces must be in a working state before a switch will forward frames on the interface. You must determine whether an interface is working, as well as determine the potential root causes for a failed switch interface.
- **Analyzing where frames will be forwarded:** You must know how to analyze a switch’s MAC address table and how to then predict how a switch will forward a particular frame.
- **Analyzing VLANs and VLAN trunking:** Keeping a Layer 2 switch focus, this last section looks at what can go wrong with VLANs and VLAN trunks.

Analyzing LAN Topology Using Cisco Discovery Protocol

The proprietary Cisco Discovery Protocol (CDP) discovers basic information about neighboring routers and switches without needing to know the passwords for the neighboring devices. To discover information, routers and switches send CDP messages out each of their interfaces. The messages essentially announce information about the device that sent the CDP message. Devices that support CDP learn information about others by listening for the advertisements sent by other devices.

As is so often the case, Cisco created CDP as a proprietary solution to meet a need for Cisco customers. Since that time, the IEEE has standardized the Link Layer Discovery Protocol (LLDP), which serves the same role. However, most enterprises that use Cisco routers and switches use CDP, with LLDP as an option, so this chapter focuses solely on CDP instead of LLDP.

From a troubleshooting perspective, CDP can be used to either confirm or fix the documentation shown in a network diagram, or even discover the devices and interfaces used in a network. Confirming that the network is actually cabled to match the network diagram is a good step to take before trying to predict the normal flow of data in a network.

On media that support multicasts at the data link layer (like Ethernet), CDP uses multicast frames; on other media, CDP sends a copy of the CDP update to any known data link addresses. So, any CDP-supporting device that shares a physical medium with another CDP-supporting device can learn about the other device.

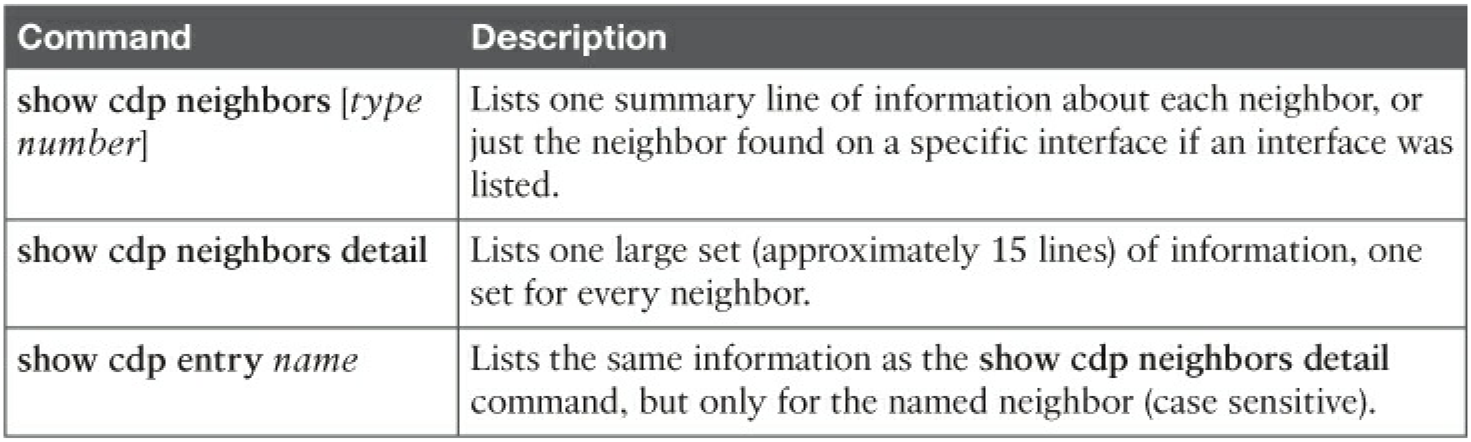
CDP discovers several useful details from the neighboring Cisco devices:

- **Device identifier:** Typically the host name
- **Address list:** Network and data link addresses
- **Port identifier:** The interface on the remote router or switch on the other end of the link that sent the CDP advertisement
- **Capabilities list:** Information on what type of device it is (for example, a router or a switch)
- **Platform:** The model and OS level running on the device

Examining Information Learned by CDP

CDP has **show** commands that list information about neighbors, **show** commands that list information about how CDP is working, and configuration commands to disable and enable CDP. Table 10-2 lists the three **show** commands that list the most important CDP information.

Table 10-2. show cdp **Commands That List Information About Neighbors**



Command	Description
show cdp neighbors [*type number*]	Lists one summary line of information about each neighbor, or just the neighbor found on a specific interface if an interface was listed.
show cdp neighbors detail	Lists one large set (approximately 15 lines) of information, one set for every neighbor.
show cdp entry *name*	Lists the same information as the **show cdp neighbors detail** command, but only for the named neighbor (case sensitive).

Note

Cisco routers and switches support the same CDP commands, with the same parameters and same types of output.

The next example shows the power of the information in CDP commands. The example uses the network shown in Figure 10-3, with Example 10-1 that follows listing the output of several **show cdp** commands.

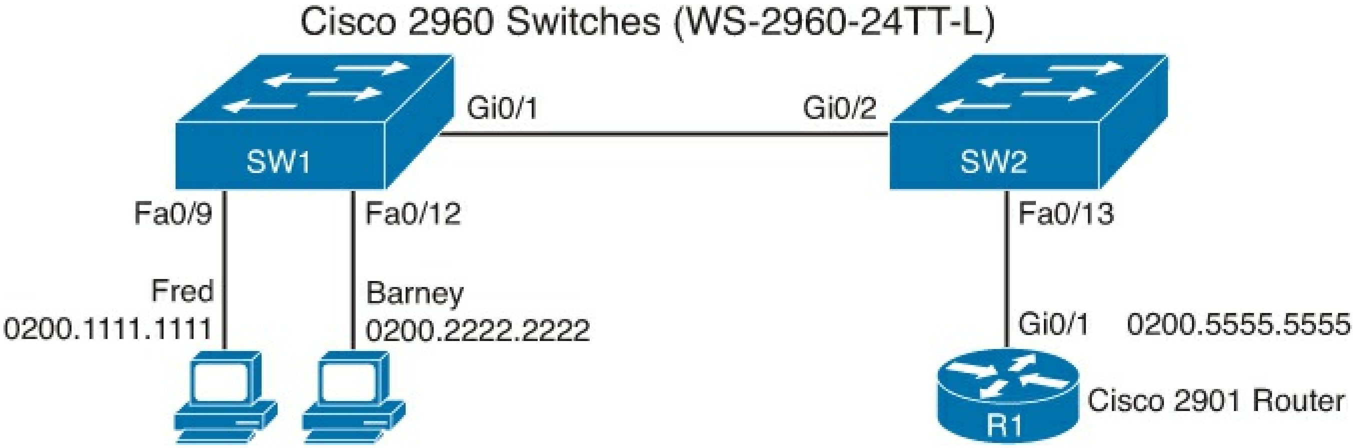


Figure 10-3. Small Network Used in CDP Examples

Example 10-1. show cdp **Command Examples: SW2**

Click here to view code image

```
! The show cdp neighbors command lists SW2's local interface, and both R1's
! and SW1's interfaces (in the "port" column), along with other details.
!
SW2# show cdp neighbors
Capability Codes: R - Router, T - Trans Bridge, B - Source Route Bridge
S - Switch, H - Host, I - IGMP, r - Repeater, P - Phone,
D - Remote, C - CVTA, M - Two-port Mac Relay

Device ID Local Intrfce Holdtme Capability Platform Port ID
SW1 Gig 0/2 170 S I WS-C2960- Gig 0/1
R1 Fas 0/13 136 R S I CISCO2901 Gig 0/1

SW2# show cdp neighbors detail
-------------------------
Device ID: SW1
Entry address(es):
IP address: 172.16.1.1
Platform: cisco WS-C2960-24TT-L, Capabilities: Switch IGMP
Interface: GigabitEthernet0/2, Port ID (outgoing port): GigabitEthernet0/1
Holdtime : 161 sec

Version :
Cisco IOS Software, C2960 Software (C2960-LANBASEK9-M), Version 15.0(1)SE3, RELEASE
SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2012 by Cisco Systems, Inc.
Compiled Wed 30-May-12 14:26 by prod_rel_team

advertisement version: 2
Protocol Hello: OUI=0x00000C, Protocol ID=0x0112; payload len=27,
value=00000000FFFFFFFF010221FF000000000000018339D7B0E80FF0000
VTP Management Domain: ''
Native VLAN: 1
Duplex: full
Management address(es):
IP address: 172.16.1.1

! This is a comment from the author: next lines are about R1.
-------------------------
Device ID: R1
Entry address(es):
IP address: 10.1.1.9
Platform: Cisco CISCO2901/K9, Capabilities: Router Switch IGMP
Interface: FastEthernet0/13, Port ID (outgoing port): GigabitEthernet0/1
Holdtime : 127 sec

Version :
Cisco IOS Software, C2900 Software (C2900-UNIVERSALK9-M), Version 15.2(4)M1, RELEASE
SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2012 by Cisco Systems, Inc.
Compiled Thu 26-Jul-12 20:54 by prod_rel_team

advertisement version: 2
VTP Management Domain: ''
Duplex: full
Management address(es):
```

The example begins with the **show cdp neighbors** command, which lists one line per neighbor. Each line lists the most important topology information: the neighbor's hostname (Device ID), the local device's interface, and the neighboring device's interface (under the Port heading). For example, SW2's **show cdp neighbors** command lists an entry for SW1, with SW2's local interface of Gi0/2 and SW1's interface of Gi0/1 (see Figure 10-3 for reference). This command also lists the platform, identifying the specific model of the neighboring router or switch. So, even using this basic information, you could either construct a figure like Figure 10-3 or confirm that the details in the figure are correct.

The **show cdp neighbors detail** command lists additional details, such as the full name of the model of switch (WS-2960-24TT-L) and the IP address configured on the neighboring device.

Note

The **show cdp entry** *name* command lists the exact same details shown in the output of the **show cdp**

neighbors detail command, but for only the one neighbor listed in the command.

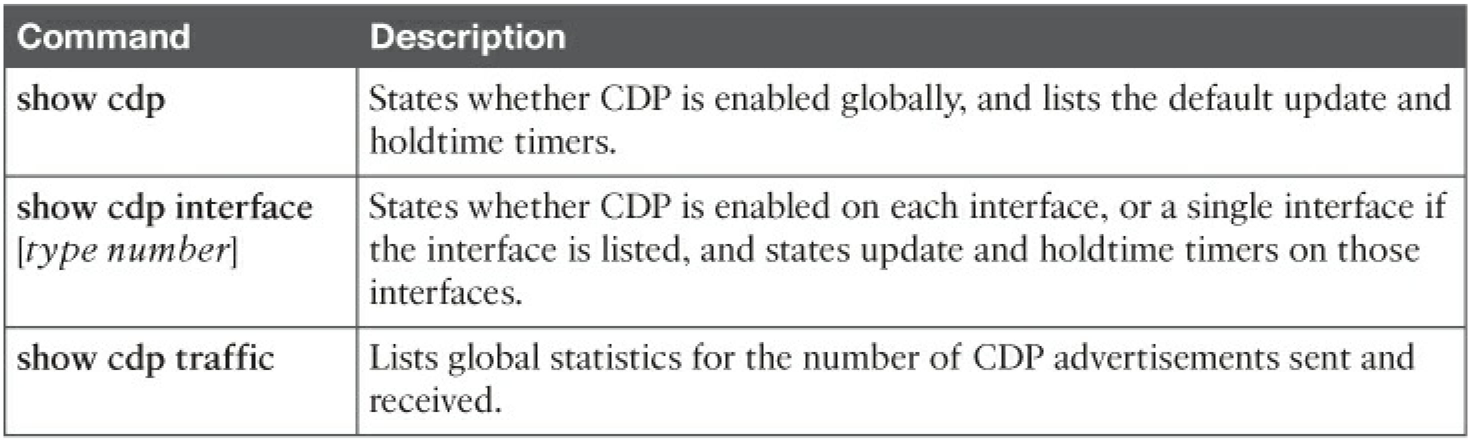
As you can see, you can sit on one device and discover a lot of information about a neighboring device—a fact that actually creates a security exposure. Cisco recommends that CDP be disabled on any interface that might not have a need for CDP. For switches, any switch port connected to another switch, a router, or to an IP phone should use CDP.

CDP can be disabled globally and per-interface. Per-interface, the **no cdp enable** and **cdp enable** interface subcommands toggle CDP off and on, respectively. Alternatively, the **no cdp run** and **cdp run** global commands toggle CDP off and on (respectively) for the entire switch.

Examining the Status of the CDP Protocols

CDP defines protocol messages that flow between devices. Cisco switches include a few commands that list statistics and other status information about how the CDP protocols are working, as summarized in Table 10-3 for easy reference.

Table 10-3. Commands Used to Verify CDP Operations



Command	Description
show cdp	States whether CDP is enabled globally, and lists the default update and holdtime timers.
show cdp interface [*type number*]	States whether CDP is enabled on each interface, or a single interface if the interface is listed, and states update and holdtime timers on those interfaces.
show cdp traffic	Lists global statistics for the number of CDP advertisements sent and received.

Example 10-2 lists sample output from each of the commands in Table 10-3, based on switch SW2 in Figure 10-3.

Example 10-2. show cdp **Commands That Show CDP Status**

Click here to view code image

```
SW2# show cdp
Global CDP information:
Sending CDP packets every 60 seconds
Sending a holdtime value of 180 seconds
Sending CDPv2 advertisements is enabled

SW2# show cdp interface FastEthernet0/13
FastEthernet0/13 is up, line protocol is up
Encapsulation ARPA
Sending CDP packets every 60 seconds
Holdtime is 180 seconds
SW2# show cdp traffic
CDP counters :
Total packets output: 304, Input: 305
Hdr syntax: 0, Chksum error: 0, Encaps failed: 0
No memory: 0, Invalid packet: 0,
CDP version 1 advertisements output: 0, Input: 0
CDP version 2 advertisements output: 304, Input: 305
```

Analyzing Switch Interface Status

This section begins the third of five major sections in this chapter by looking at switch interfaces. That process begins with finding out whether each switch interface works. Unsurprisingly, Cisco switches do not use interfaces at all unless the interface is first considered to be in a functional or working state. Additionally, the switch interface might be in a working state, but intermittent problems might still be occurring.

This section begins by looking at the Cisco switch interface status codes and what they mean so that you can know whether an interface is working. The rest of this section then looks at those more unusual cases in which the interface is working, but not working well.

Interface Status Codes and Reasons for Nonworking States

Cisco switches actually use two different sets of interface status codes—one set of two codes (words) that use the same conventions as do router interface status codes, and another set with a single code (word). Both sets of status codes can determine whether an interface is working.

The switch **show interfaces** and **show interfaces description** commands list the two-code status just like routers. The two codes are named the *line status* and *protocol status*. They *generally* refer to whether Layer 1 is working (line status) and whether Layer 2 is working (protocol status), respectively. LAN switch interfaces typically show an interface with both codes with the same value, either "up" or "down."

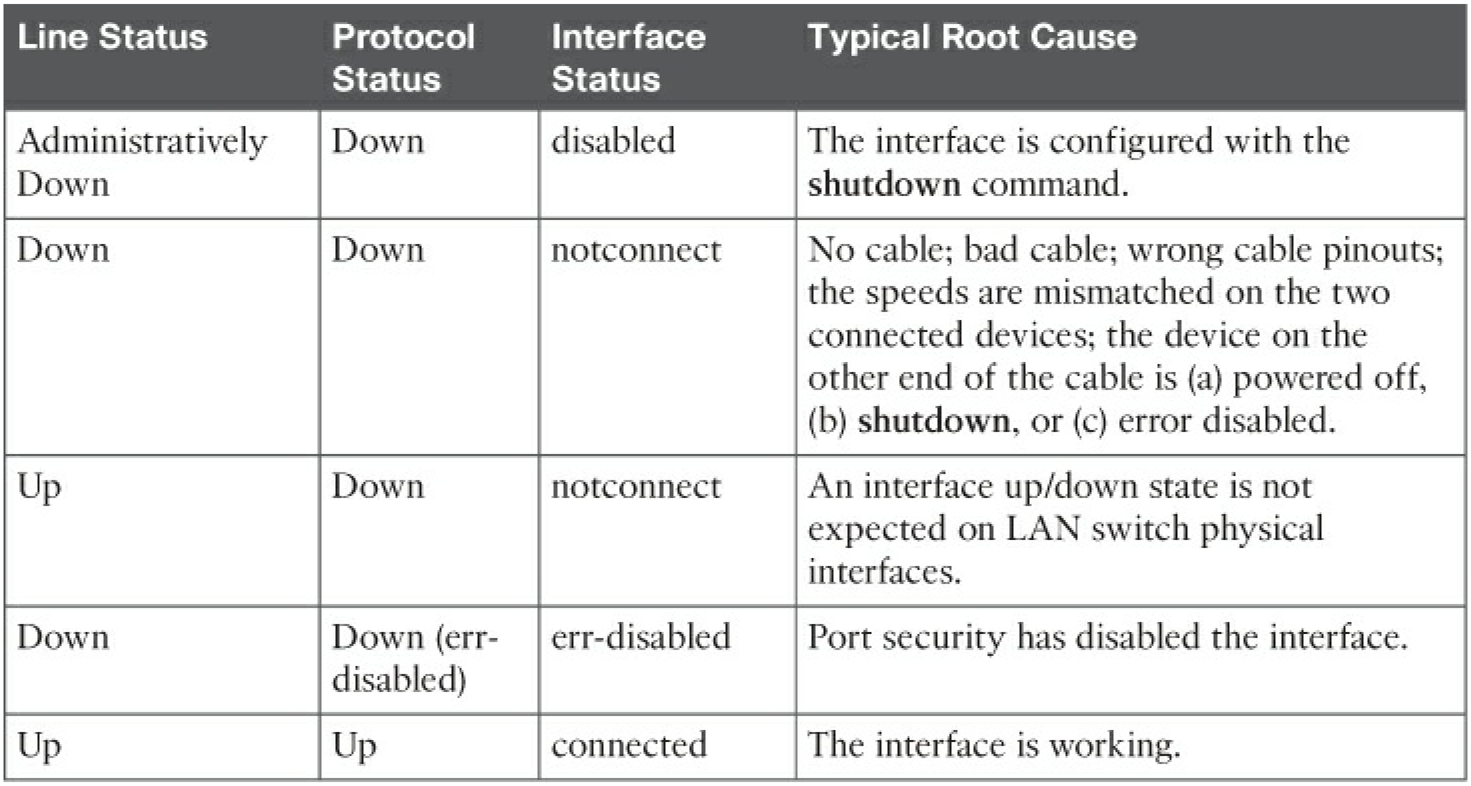
> **Note**
>
> This book refers to these two status codes in shorthand by just listing the two codes with a slash between them, such as "up/up."

The **show interfaces status** command lists a different single interface status code. This single interface status code corresponds to different combinations of the traditional two-code interface status codes and can be easily correlated to those codes. For example, the **show interfaces status** command lists a "connected" state for working interfaces. It corresponds to the up/up state seen with the **show interfaces** and **show interfaces description** commands.

Any interface state other than *connected* or *up/up* means that the switch will not forward or receive frames on the interface. Each nonworking interface state has a small set of root causes. Also, note that the exams could easily ask a question that showed only one or the other type of status code, so be prepared to see both types of status codes on the exams, and know the meanings of both. Table 10-4 lists the code combinations and some root causes that could have caused a particular interface status.

Key Topic

Table 10-4. LAN Switch Interface Status Codes



Line Status	Protocol Status	Interface Status	Typical Root Cause
Administratively Down	Down	disabled	The interface is configured with the **shutdown** command.
Down	Down	notconnect	No cable; bad cable; wrong cable pinouts; the speeds are mismatched on the two connected devices; the device on the other end of the cable is (a) powered off, (b) **shutdown**, or (c) error disabled.
Up	Down	notconnect	An interface up/down state is not expected on LAN switch physical interfaces.
Down	Down (err-disabled)	err-disabled	Port security has disabled the interface.
Up	Up	connected	The interface is working.

Most of the reasons for the notconnect state were covered earlier in this book. For example, using incorrect cabling pinouts, instead of the correct pinouts explained in Chapter 2, "Fundamentals of Ethernet LANs," causes a problem. However, one topic can be particularly difficult to troubleshoot—the possibility for both speed and duplex mismatches, as explained in the next section.

As you can see in the table, having a bad cable is just one of many reasons for the down/down state (or notconnect, per the **show interfaces status** command). Interestingly, the Cisco CCENT and CCNA exams do not focus much on cabling itself. However, for some examples of the root causes of cabling problems:

- The installation of any equipment that uses electricity, even non-IT equipment, can interfere with the transmission on the cabling, and make the link fail.
- The cable could be damaged, for example, if it lies under carpet. If the user's chair keeps squashing the cable,

eventually the electrical signal can degrade.

- While optical cables do not suffer from EMI, someone can try to be helpful and move a fiber-optic cable out of the way—bending it too much. A bend into too tight a shape can prevent the cable from transmitting bits (called *macrobending*).

For the other interface states listed in Table 10-4, only the up/up (connected) state needs more discussion. An interface can be in a working state, and it might really be working—or it might be working in a degraded state. The next few topics discuss how to examine an up/up interface to find out whether it is working well or having problems.

Interface Speed and Duplex Issues

Many UTP-based Ethernet interfaces support multiple speeds, either full-or half-duplex, and support IEEE standard autonegotiation (as discussed in Chapter 6's section "Autonegotiation"). These same interfaces can also be configured to use a specific speed using the **speed** {**10** | **100** | **1000**} interface subcommand, and a specific duplex using the **duplex** {**half** | **full**} interface subcommand. With both configured, a switch or router disables the IEEE-standard autonegotiation process on that interface.

The **show interfaces** and **show interfaces status** commands list both the actual speed and duplex settings on an interface, as demonstrated in Example 10-3.

Key Topic

Example 10-3. Displaying Speed and Duplex Settings on Switch Interfaces

Click here to view code image

```
SW1# show interfaces status

Port Name Status Vlan Duplex Speed Type
Fa0/1 notconnect 1 auto auto 10/100BaseTX
Fa0/2 notconnect 1 auto auto 10/100BaseTX
Fa0/3 notconnect 1 auto auto 10/100BaseTX
Fa0/4 connected 1 a-full a-100 10/100BaseTX
Fa0/5 connected 1 a-full a-100 10/100BaseTX
Fa0/6 notconnect 1 auto auto 10/100BaseTX
Fa0/7 notconnect 1 auto auto 10/100BaseTX
Fa0/8 notconnect 1 auto auto 10/100BaseTX
Fa0/9 notconnect 1 auto auto 10/100BaseTX
Fa0/10 notconnect 1 auto auto 10/100BaseTX
Fa0/11 connected 1 a-full 10 10/100BaseTX
Fa0/12 connected 1 half 100 10/100BaseTX
Fa0/13 connected 1 a-full a-100 10/100BaseTX
Fa0/14 disabled 1 auto auto 10/100BaseTX
Fa0/15 notconnect 3 auto auto 10/100BaseTX
Fa0/16 notconnect 3 auto auto 10/100BaseTX
Fa0/17 connected 1 a-full a-100 10/100BaseTX
Fa0/18 notconnect 1 auto auto 10/100BaseTX
Fa0/19 notconnect 1 auto auto 10/100BaseTX
Fa0/20 notconnect 1 auto auto 10/100BaseTX
Fa0/21 notconnect 1 auto auto 10/100BaseTX
Fa0/22 notconnect 1 auto auto 10/100BaseTX
Fa0/23 notconnect 1 auto auto 10/100BaseTX
Fa0/24 notconnect 1 auto auto 10/100BaseTX
Gi0/1 connected trunk full 1000 10/100/1000BaseTX
Gi0/2 notconnect 1 auto auto 10/100/1000BaseTX

SW1# show interfaces fa0/13
FastEthernet0/13 is up, line protocol is up (connected)
Hardware is Fast Ethernet, address is 0019.e86a.6f8d (bia 0019.e86a.6f8d)
MTU 1500 bytes, BW 100000 Kbit, DLY 100 usec,
reliability 255/255, txload 1/255, rxload 1/255
Encapsulation ARPA, loopback not set
Keepalive set (10 sec)
Full-duplex, 100Mbps, media type is 10/100BaseTX
input flow-control is off, output flow-control is unsupported
ARP type: ARPA, ARP Timeout 04:00:00
Last input 00:00:05, output 00:00:00, output hang never
Last clearing of "show interface" counters never
```

```
    Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
    Queueing strategy: fifo
    Output queue: 0/40 (size/max)
    5 minute input rate 0 bits/sec, 0 packets/sec
    5 minute output rate 0 bits/sec, 0 packets/sec
    85022 packets input, 10008976 bytes, 0 no buffer
    Received 284 broadcasts (0 multicast)
    0 runts, 0 giants, 0 throttles
    0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored
    0 watchdog, 281 multicast, 0 pause input
    0 input packets with dribble condition detected
    95226 packets output, 10849674 bytes, 0 underruns
    0 output errors, 0 collisions, 1 interface resets
    0 unknown protocol drops
    0 babbles, 0 late collision, 0 deferred
    0 lost carrier, 0 no carrier, 0 PAUSE output
    0 output buffer failures, 0 output buffers swapped out
```

Although both commands in the example can be useful, only the **show interfaces status** command implies how the switch determined the speed and duplex settings. The command output lists autonegotiated settings with a prefix of **a-**. For example, **a-full** means full-duplex as autonegotiated, whereas **full** means full-duplex but as manually configured. The example shades the command output that implies that the switch's Fa0/12 interface's speed and duplex were not found through autonegotiation, but Fa0/13 did use autonegotiation. Note that the **show interfaces fa0/13** command (without the **status** option) simply lists the speed and duplex for interface Fast Ethernet 0/13, with nothing implying that the values were learned through autonegotiation.

When the IEEE autonegotiation process works on both devices, both devices agree to the fastest speed supported by both devices. Additionally, the devices use full-duplex if it is supported by both devices, or half-duplex if it is not. However, when one device has disabled autonegotiation, and the other device uses autonegotiation, the device using autonegotiation chooses the default duplex setting based on the current speed. The defaults are as follows:

Key Topic

- If the speed is not known through any means, use 10 Mbps, half-duplex.
- If the switch successfully senses the speed without IEEE autonegotiation, by just looking at the signal on the cable:
  - If the speed is 10 or 100 Mbps, default to use half-duplex.
  - If the speed is 11,000 Mbps, default to use full-duplex.

Note

Ethernet interfaces using speeds faster than 1 Gbps always use full-duplex.

While autonegotiation works well, these defaults allow for the possibility of a difficult-to-troubleshoot problem called a *duplex mismatch*. Chapter 6's section "Autonegotiation" explains how both devices could use the same speed, so the devices would consider the link to be up, but one side would use half-duplex, and the other side would use full-duplex.

The next example shows a specific case that causes a duplex mismatch. In Figure 10-4, imagine that SW2's Gi0/2 interface was configured with the **speed 100** and **duplex full** commands (these settings are not recommended on a Gigabit-capable interface, by the way). On Cisco switches, configuring both the **speed** and **duplex** commands disables IEEE autonegotiation on that port. If SW1's Gi0/1 interface tries to use autonegotiation, SW1 would also use a speed of 100 Mbps, but default to use half-duplex. Example 10-4 shows the results of this specific case on SW1.

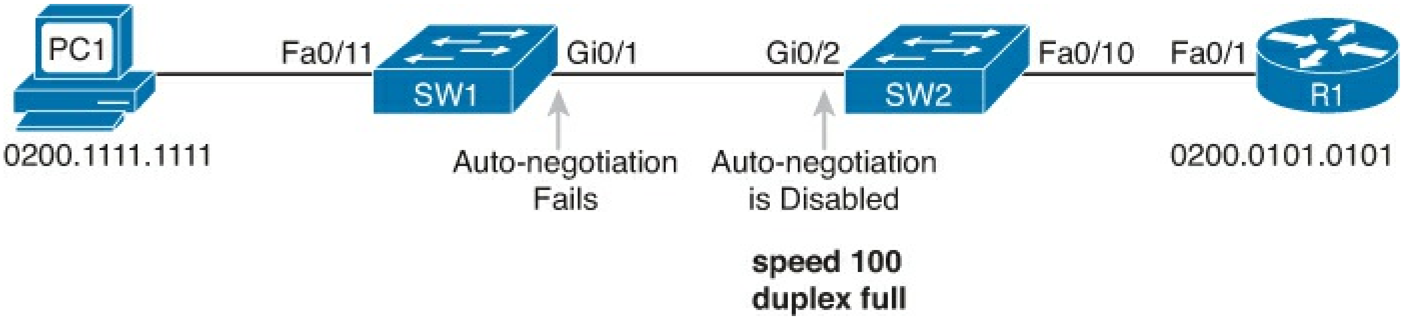


Figure 10-4. Conditions to Create a Duplex Mismatch Between SW1 and SW2

Example 10-4. Confirming Duplex Mismatch on Switch SW1

Click here to view code image

```
SW1# show interfaces gi0/1 status

Port Name Status Vlan Duplex Speed Type
Gi0/1 connected trunk a-half a-100 10/100/1000BaseTX
```

First, focusing on the command output, the command confirms SW1's speed and duplex. It also lists a prefix of **a-** in the output, implying autonegotiation. Even with SW1 using autonegotiation defaults, the command still notes the values as being learned through autonegotiation.

Finding a duplex mismatch can be much more difficult than finding a speed mismatch, because *if the duplex settings do not match on the ends of an Ethernet segment, the switch interface will still be in a connected (up/up) state*. In this case, the interface works, but it might work poorly, with poor performance, and with symptoms of intermittent problems. The reason is that the device using half-duplex uses carrier sense multiple access collision detect (CSMA/CD) logic, waiting to send when receiving a frame, believing collisions occur when they physically do not—and actually stopping sending a frame because the switch thinks a collision occurred. With enough traffic load, the interface could be in a connect state, but it's extremely inefficient for passing traffic.

To identify duplex mismatch problems, check the duplex setting on each end of the link and watch for incrementing collision and late collision counters, as explained in the next section.

Common Layer 1 Problems on Working Interfaces

When the interface reaches the connect (up/up) state, the switch considers the interface to be working. The switch, of course, tries to use the interface, and at the same time, the switch keeps various interface counters. These interface counters can help identify problems that can occur even though the interface is in a connect state. This section explains some of the related concepts and a few of the most common problems.

Whenever the physical transmission has problems, the receiving device might receive a frame whose bits have changed values. These frames do not pass the error detection logic as implemented in the FCS field in the Ethernet trailer, as covered in Chapter 2. The receiving device discards the frame and counts it as some kind of *input error*. Cisco switches list this error as a CRC error, as highlighted in Example 10-5. (Cyclic redundancy check [CRC] is a term related to how the FCS math detects an error.)

Example 10-5. Interface Counters for Layer 1 Problems

Click here to view code image

```
SW1# show interfaces fa0/13
! lines omitted for brevity
Received 284 broadcasts (0 multicast)
0 runts, 0 giants, 0 throttles
0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored
0 watchdog, 281 multicast, 0 pause input
0 input packets with dribble condition detected
95226 packets output, 10849674 bytes, 0 underruns
0 output errors, 0 collisions, 1 interface resets
0 unknown protocol drops
0 babbles, 0 late collision, 0 deferred
0 lost carrier, 0 no carrier, 0 PAUSE output
0 output buffer failures, 0 output buffers swapped out
```

The number of input errors, and the number of CRC errors, are just a few of the counters in the output of the **show interfaces** command. The challenge is to decide which counters you need to think about, which ones show that a problem is happening, and which ones are normal and of no concern.

The example highlights several of the counters as examples so that you can start to understand which ones point to problems and which ones are just counting normal events that are not problems. The following list shows a short description of each highlighted counter, in the order shown in the example:

Runts: Frames that did not meet the minimum frame size requirement (64 bytes, including the 18-byte destination MAC, source MAC, Type, and FCS). Can be caused by collisions.

Giants: Frames that exceed the maximum frame size requirement (1518 bytes, including the 18-byte destination MAC, source MAC, Type, and FCS).

Input Errors: A total of many counters, including runts, giants, no buffer, CRC, frame, overrun, and ignored counts.

CRC: Received frames that did not pass the FCS math; can be caused by collisions.

Frame: Received frames that have an illegal format, for example, ending with a partial byte; can be caused by collisions.

Packets Output: Total number of packets (frames) forwarded out the interface.

Output Errors: Total number of packets (frames) that the switch port tried to transmit, but for which some problem occurred.

Collisions: Counter of all collisions that occur when the interface is transmitting a frame.

Late Collisions: The subset of all collisions that happen after the 64th byte of the frame has been transmitted. (In a properly working Ethernet LAN, collisions should occur within the first 64 bytes; late collisions today often point to a duplex mismatch.)

Note that many of these counters occur as part of the CSMA/CD process used when half-duplex is enabled. Collisions occur as a normal part of the half-duplex logic imposed by CSMA/CD, so a switch interface with an increasing collisions counter might not even have a problem. However, one problem, called late collisions, points to the classic duplex mismatch problem.

If a LAN design follows cabling guidelines, all collisions should occur by the end of the 64th byte of any frame. When a switch has already sent 64 bytes of a frame, and the switch receives a frame on that same interface, the switch senses a collision. In this case, the collision is a late collision, and the switch increments the late collision counter in addition to the usual CSMA/CD actions to send a jam signal, wait a random time, and try again.

With a duplex mismatch, like the mismatch between SW1 and SW2 in Figure 10-4, the half-duplex interface will likely see the late collisions counter increment. Why? The half-duplex interface sends a frame (SW1), but the full-duplex neighbor (SW2) sends at any time, even after the 64th byte of the frame sent by the half-duplex switch. So, just keep repeating the **show interfaces** command, and if you see the late collisions counter incrementing on a half-duplex interface, you might have a duplex mismatch problem.

A working interface (in an up/up state) can still suffer from issues related to the physical cabling as well. The cabling problems might not be bad enough to cause a complete failure, but the transmission failures result in some frames failing to pass successfully over the cable. For example, excessive interference on the cable can cause the various input error counters to keep growing larger, especially the CRC counter. In particular, if the CRC errors grow, but the collisions counters do not, the problem might simply be interference on the cable. (The switch counts each collided frame as one form of input error as well.)

Predicting Where Switches Will Forward Frames

This section begins the fourth of five major sections in this chapter. This section looks at a key part of the troubleshooting process for Ethernet LANs: predicting where frames should go in the LAN so that you can compare what should happen versus what is actually happening in a LAN.

Predicting the Contents of the MAC Address Table

As explained in Chapter 6, "Building Ethernet LANs with Switches," switches learn MAC addresses and then use the entries in the MAC address table to make a forwarding/filtering decision for each frame. To know exactly how a particular switch will forward an Ethernet frame, you need to examine the MAC address table on a Cisco switch.

The **show mac address-table** EXEC command displays the contents of a switch's MAC address table. This command lists all MAC addresses currently known by the switch. The output includes some static overhead MAC addresses used by the switch and any statically configured MAC addresses, such as those configured with the port security feature. The command also lists all dynamically learned MAC addresses. If you want to see only the dynamically learned MAC address table entries, simply use the **show mac address-table dynamic** EXEC command.

Note

Some older switch IOS versions only support the older version of this command: **show mac-address-table**.

The more formal troubleshooting process begins with a mental process where you predict where frames should flow in the LAN. As an exercise, go back and review Figure 10-3 and try to create a MAC address table on paper for each switch. Include the MAC addresses for both PCs, as well as the Gi0/1 MAC address for R1. (Assume that all three are assigned to VLAN 10.) Then predict which interfaces would be used to forward a frame sent by Fred, Barney, and R1 to every other device.

The MAC table entries you predict in this case define where you think frames will flow. Even though this sample network in Figure 10-3 shows only one physical path through the Ethernet LAN, the exercise should be worthwhile, because it forces you to correlate what you'd expect to see in the MAC address table with how the switches forward frames. Figure 10-5 shows the resulting MAC table entries for PCs Fred and Barney, as well as for Router R1.

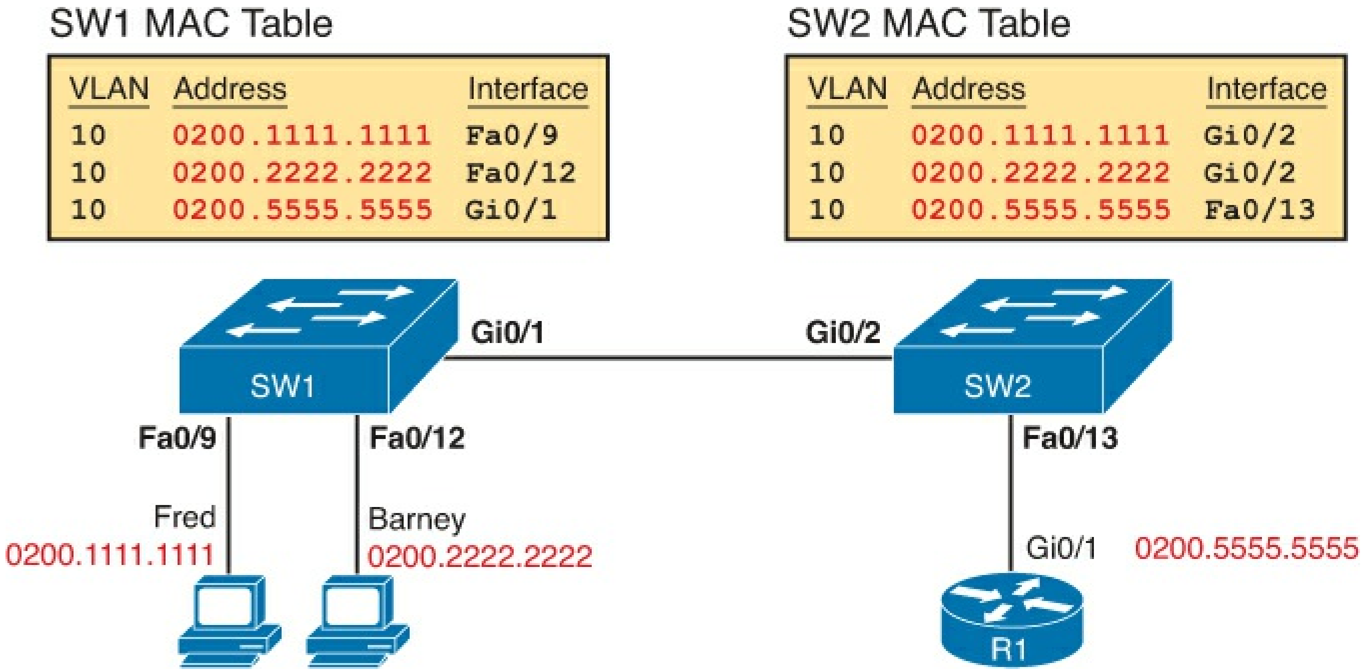

SW1 MAC Table
VLAN Address Interface
10 0200.1111.1111 Fa0/9
10 0200.2222.2222 Fa0/12
10 0200.5555.5555 Gi0/1
SW2 MAC Table
VLAN Address Interface
10 0200.1111.1111 Gi0/2
10 0200.2222.2222 Gi0/2
10 0200.5555.5555 Fa0/13
SW1
Gi0/1
Gi0/2
SW2
Fa0/9
Fa0/12
Fa0/13
Fred
0200.1111.1111
Barney
0200.2222.2222
Gi0/1
0200.5555.5555
R1

Figure 10-5. Predictions for MAC Table Entries on SW1 and SW2

While Figure 10-5 shows the concepts, Example 10-6 lists the same facts but in the form of the **show mac address-table dynamic** command on the switches. This command lists all dynamically learned MAC table entries on a switch, for all VLANs.

Example 10-6. Examining SW1 and SW2 Dynamic MAC Address Table Entries

Click here to view code image

```
SW1# show mac address-table dynamic
Mac Address Table
-------------------------------------------

Vlan Mac Address Type Ports
---- ----------- -------- -----
10 0200.1111.1111 DYNAMIC Fa0/9
10 0200.2222.2222 DYNAMIC Fa0/12
10 0200.5555.5555 DYNAMIC Gi0/1
```

```
SW2# show mac address-table dynamic
Mac Address Table
-------------------------------------------

Vlan Mac Address Type Ports
---- ----------- -------- -----
10 0200.1111.1111 DYNAMIC Gi0/2
10 0200.2222.2222 DYNAMIC Gi0/2
10 0200.5555.5555 DYNAMIC Fa0/13
```

When predicting the MAC address table entries, you need to imagine a frame sent by a device to another device on the other side of the LAN and then determine *which switch ports the frame would enter* as it passes through the LAN. For example, if Barney sends a frame to Router R1, the frame would enter SW1's Fa0/12 interface, so SW1 has a MAC table entry that lists Barney's 0200.2222.2222 MAC address with Fa0/12. SW1 would forward Barney's frame to SW2, arriving on SW2's Gi0/2 interface, so SW2's MAC table lists Barney's MAC address (0200.2222.2222) with interface Gi0/2.

After you predict the expected contents of the MAC address tables, you can then examine what is actually happening on the switches, as described in the next section.

Analyzing the Forwarding Path

Troubleshooting revolves around three big ideas: predicting what should happen, determining what is happening that is different than what should happen, and figuring out why that different behavior is happening. This next section discusses how to look at what is actually happening in a VLAN based on those MAC address tables, first using a summary of switch forwarding logic and then showing an example.

The following list summarizes switch forwarding logic including the LAN switching features discussed in this book:

Step 1. Process functions on the incoming interface, if the interface is currently in an up/up (connected) state, as follows:

- **A.** If configured, apply port security logic to filter the frame as appropriate.
- **B.** If the port is an access port, determine the interface's access VLAN.
- **C.** If the port is a trunk, determine the frame's tagged VLAN.

Step 2. Make a forwarding decision. Look for the frame's destination MAC address in the MAC address table, but only for entries in the VLAN identified in Step 1. If the destination MAC is...

- **A. Found (unicast),** forward the frame out the only interface listed in the matched address table entry.
- **B. Not found (unicast),** flood the frame out all other access ports (except the incoming port) in that same VLAN, plus out trunks that have not restricted the VLAN from that trunk (as discussed in Chapter 9, "Implementing Ethernet Virtual LANs," as related to the **show interfaces trunk** command).
- **C. Broadcast,** flood the frame, with the same rules as the previous step.

For an example of this process, consider a frame sent by Barney to its default gateway, R1 (0200.5555.5555). Using the steps just listed, the following occurs:

Step 1. Input interface processing:

- **A.** The port does not happen to have port security enabled.
- **B.** SW1 receives the frame on its Fa0/12 interface, an access port in VLAN 10.

Step 2. Make a forwarding decision: SW1 looks in its MAC address table for entries in VLAN 10:

- **A.** SW1 finds an entry (known unicast) for 0200.5555.5555, associated with VLAN 10, outgoing interface Gi0/1, so SW1 forwards the frame only out interface Gi0/1. (This link is a VLAN trunk, so SW1 adds a VLAN 10 tag to the 802.1Q trunking header.)

At this point, the frame with source 0200.2222.2222 (Barney) and destination 0200.5555.5555 (R1) is on its way to SW2. You can then apply the same logic for SW2, as follows:

Step 1. Input interface processing:

- **A.** The port does not happen to have port security enabled.
- **B.** SW2 receives the frame on its Gi0/2 interface, a trunk; the frame lists a tag of VLAN 10. (SW2 will remove the 802.1Q header as well.)

Step 2. Make a forwarding decision: SW2 looks for its MAC table for entries in VLAN 10:

- **A.** SW2 finds an entry (known unicast) for 0200.5555.5555, associated with VLAN 10, outgoing interface Fa0/13, so SW2 forwards the frame only out interface Fa0/13.

At this point, the frame should be on its way, over the Ethernet cable between SW2 and R1.

Port Security and Filtering

When tracing the path a frame takes through LAN switches, different kinds of filters can discard frames, even when all the interfaces are up. For example, LAN switches can use filters called access control lists (ACL) that filter based on the source and destination MAC address, discarding some frames. Additionally, routers can filter IP packets using IP ACLs. (This book does not discuss ACLs for LAN switches, but it does discuss IP ACLs for routers in Chapter 22, "Basic IPv4 Access Control Lists," and Chapter 23, "Advanced IPv4 ACLs and Device Security.")

Additionally, port security, as discussed in Chapter 8, "Configuring Ethernet Switching," also filters frames. In some cases, you can easily tell that port security has taken action, because port security shuts down the interface. However, in other cases, port security leaves the interface up, but simply discards the offending traffic. From a troubleshooting perspective, a port security configuration that leaves the interface up, but still discards frames, requires the network engineer to look closely at port security status, rather than just looking at interfaces and the MAC address table.

As a reminder, port security allows three violation modes (**shutdown**, **protect**, and **restrict**), but only the default setting of **shutdown** causes the switch to err-disable the interface.

For example, consider a case in which someone takes a working network and adds port security to filter frames sent by Barney. Use Figure 10-3 or 10-5, both of which show the same topology. Barney sends frames into SW1's Fa0/12 port, which is now configured with port security. The port security configuration considers frames with Barney's source MAC address as a violation, and it uses a violation mode set to **protect**.

What happens? SW1 now discards all frames sourced by Barney's MAC address. But SW1 does not disable any interfaces. The **show interfaces** or **show interfaces status** command on SW1 shows no changes to the interface status, and no evidence of what happened. You would need to look further at port security (**show port-security interface**) to find evidence that port security was discarding the frames sent by Barney.

The MAC address table gives some hints that port security might be enabled. Because port security manages the MAC addresses, any MAC addresses associated with a port on which port security is enabled show up as static MAC addresses. As a result, the **show mac address-table dynamic** command does not list MAC addresses off these interfaces on which port security is enabled. However, the **show mac address-table** and **show mac address-table static** commands do list these static MAC addresses.

Analyzing VLANs and VLAN Trunks

A switch's forwarding process, as discussed earlier in the section "Analyzing the Forwarding Path," depends in part on VLANs and VLAN trunking. Before a switch can forward frames in a particular VLAN, the switch must know about a VLAN and the VLAN must be active. And before a switch can forward a frame over a VLAN trunk, the trunk must currently allow that VLAN to pass over the trunk.

This final of the five major sections in this chapter focuses on VLAN and VLAN trunking issues, and specifically issues that impact the frame switching process. The four potential issues are as follows:

Step 1. Identify all access interfaces and their assigned access VLANs and reassign into the correct VLANs as needed.

Step 2. Determine whether the VLANs both exist (configured or learned with VTP) and are active on each switch. If not, configure and activate the VLANs to resolve problems as needed.

Step 3. Check the allowed VLAN lists, on the switches on both ends of the trunk, and ensure that the lists of allowed VLANs are the same.

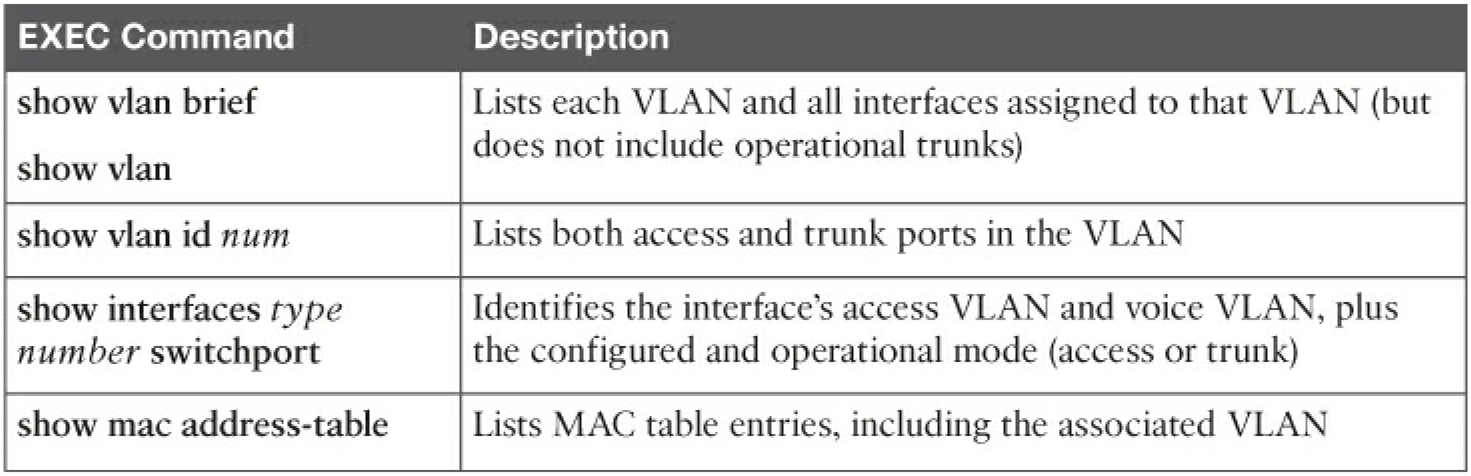
Step 4. Ensure that for any links that should use trunking, one switch does not think it is trunking, while the other switch does not think it is trunking because of an unfortunate choice of configuration settings.

Ensuring That the Right Access Interfaces Are in the Right VLANs

To ensure that each access interface has been assigned to the correct VLAN, engineers simply need to determine which switch interfaces are access interfaces instead of trunk interfaces, determine the assigned access VLANs on each interface, and compare the information to the documentation. The **show** commands listed in Table 10-5 can be particularly helpful in this process.

Key Topic

Table 10-5. Commands That Can Find Access Ports and VLANs



EXEC Command	Description
show vlan brief show vlan	Lists each VLAN and all interfaces assigned to that VLAN (but does not include operational trunks)
show vlan id *num*	Lists both access and trunk ports in the VLAN
show interfaces *type number* switchport	Identifies the interface's access VLAN and voice VLAN, plus the configured and operational mode (access or trunk)
show mac address-table	Lists MAC table entries, including the associated VLAN

If possible, start this step with the **show vlan** and **show vlan brief** commands, because they list all the known VLANs and the access interfaces assigned to each VLAN. Be aware, however, that these two commands do not list operational trunks. The output does list all other interfaces (those not currently trunking), no matter whether the interface is in a working or nonworking state.

If the **show vlan** and **show interface switchport** commands are not available in a particular exam question, the **show mac address-table** command can also help identify the access VLAN. This command lists the MAC address table, with each entry including a MAC address, interface, and VLAN ID. If the exam question implies that a switch interface connects to a single device PC, you should only see one MAC table entry that lists that particular access interface; the VLAN ID listed for that same entry identifies the access VLAN. (You cannot make such assumptions for trunking interfaces.)

After you determine the access interfaces and associated VLANs, if the interface is assigned to the wrong VLAN, use the **switchport access vlan** *vlan-id* interface subcommand to assign the correct VLAN ID.

Access VLANs Not Being Defined

Switches do not forward frames for VLANs that are (a) not configured or (b) configured but disabled (shutdown). This section summarizes the best ways to confirm that a switch knows that a particular VLAN exists, and if it exists, determines the state of the VLAN.

First, on the issue of whether a VLAN is defined, a VLAN can be defined to a switch in two ways: using the **vlan** *number* global configuration command, or it can be learned from another switch using VTP. This book purposefully ignores VTP as much as possible, so for this discussion, consider that the only way for a switch to know about a VLAN is to have a **vlan** command configured on the local switch.

Next, the **show vlan** command always lists all VLANs known to the switch, but the **show running-config** command does not. Switches configured as VTP servers and clients do not list the **vlan** commands in the running-config nor the startup-config file; on these switches, you must use the **show vlan** command. Switches configured to use VTP transparent mode, or that disable VTP, list the **vlan** configuration commands in the configuration files. (Use the **show vtp status** command to learn the current VTP mode of a switch.)

After you determine that a VLAN does not exist, the problem might be that the VLAN simply needs to be defined. If so, follow the VLAN configuration process as covered in detail in Chapter 9.

Access VLANs Being Disabled

For any existing VLANs, also verify that the VLAN is active. The **show vlan** command should list one of two VLAN state values, depending on the current state: either *active* or *act/lshut*. The second of these states means that the VLAN is shutdown. Shutting down a VLAN disables the VLAN on that switch only, so that *the switch will not forward frames in that VLAN*.

Switch IOS gives you two similar configuration methods with which to disable (**shutdown**) and enable (**no shutdown**) a VLAN. Example 10-7 shows how, first by using the global command [**no] shutdown vlan** *number* and then using the VLAN mode subcommand **[no] shutdown**. The example shows the global commands enabling and disabling VLANs 10 and 20, respectively, and using VLAN subcommands to enable and disable VLANs 30 and 40 (respectively).

Example 10-7. Enabling and Disabling VLANs on a Switch

Click here to view code image

```
SW2# show vlan brief

VLAN Name Status Ports
---- -------------------------------- --------- -------------------------------
1 default active Fa0/1, Fa0/2, Fa0/3, Fa0/4
Fa0/5, Fa0/6, Fa0/7, Fa0/8
Fa0/9, Fa0/10, Fa0/11, Fa0/12
Fa0/14, Fa0/15, Fa0/16, Fa0/17
Fa0/18, Fa0/19, Fa0/20, Fa0/21
Fa0/22, Fa0/23, Fa0/24, Gi0/1
10 VLAN0010 act/lshut Fa0/13
20 VLAN0020 active
30 VLAN0030 act/lshut
40 VLAN0040 active
SW2#configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
SW2(config)# no shutdown vlan 10
SW2(config)# shutdown vlan 20
SW2(config)# vlan 30
SW2(config-vlan)# no shutdown
SW2(config-vlan)# vlan 40
SW2(config-vlan)# shutdown
SW2(config-vlan)#
```

Check the Allowed VLAN List on Both Ends of a Trunk

The next item, and the one that follows, both occur when an engineer makes some poor configuration choices on a VLAN trunk. In real life, you should instead just configure the trunk correctly, as outlined in Chapter 9's section "VLAN Trunking Configuration" and the section that follows it, "Controlling Which VLANs Can Be Supported on a Trunk." But for the exams, you should be ready to notice a couple of oddities that happen with some unfortunate configuration choices on trunks.

First, it is possible to configure a different allowed VLAN list on the opposite ends of a VLAN trunk. When mismatched, the trunk cannot pass traffic for that VLAN.

Figure 10-6 shows an example. Both switches have defined VLANs 1 through 10, so both by default include VLANs 1 through 10 in their allowed VLAN list. However, SW2 has been configured with a **switchport trunk allowed vlan remove 10** command, removing VLAN 10 from SW2's G0/2 allowed list. In this case, SW1, which still allows VLAN 10, acts as normal, tagging and forwarding frames in VLAN 10 (Step 1 in the figure). SW2 simply discards any VLAN 10 frames received on that trunk (Step 2), because SW2 does not allow VLAN 10 traffic on that trunk.

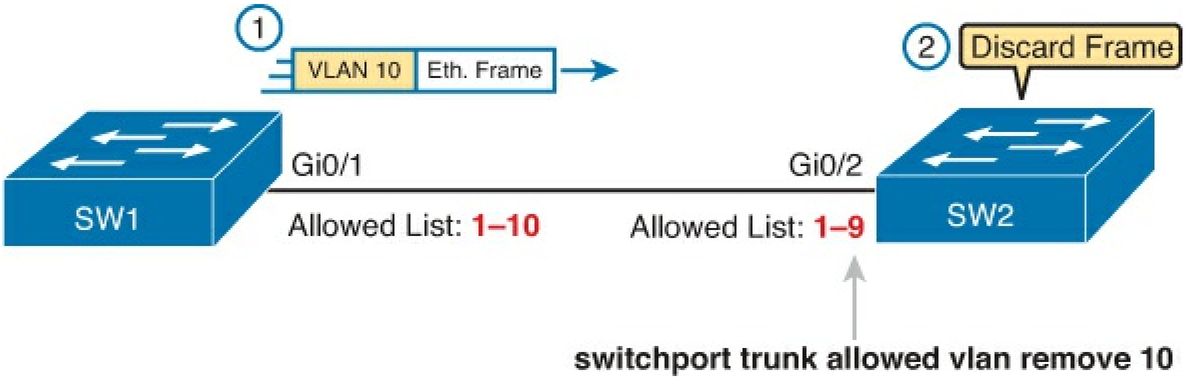


Figure 10-6. Mismatched VLAN-Allowed Lists on a Trunk

And to emphasize the point, you cannot see this problem from just one side of the trunk or the other. The **show interfaces trunk** command output on both sides looks completely normal. You can only notice the problem by comparing the allowed lists on both ends of the trunk.

To compare the lists, you need to look at the second of three lists of VLANs listed by the **show interfaces trunk** command, as highlighted in the example output in Example 10-8. The highlighted text shows the second section, which lists VLANs that meet these criteria: the VLANs that exist on the switch, that are not shutdown, and that are not removed from the allowed list.

Example 10-8. Second Set of VLANs: Existing, Not Shut Down, and Allowed

Click here to view code image

```
SW2# show interfaces trunk

Port Mode Encapsulation Status Native vlan
Gi0/2 desirable 802.1q trunking 1

Port Vlans allowed on trunk
Gi0/2 1-4094

Port Vlans allowed and active in management domain
Gi0/2 1-9

Port Vlans in spanning tree forwarding state and not pruned
Gi0/2 1-9
```

Mismatched Trunking Operational States

Trunking can be configured correctly so that both switches forward frames for the same set of VLANs. However, trunks can also be misconfigured, with a couple of different results. In some cases, both switches conclude that their interfaces do not trunk. In other cases, one switch believes that its interface is correctly trunking, while the other switch does not.

The most common incorrect configuration—which results in both switches not trunking—is a configuration that uses the **switchport mode dynamic auto** command on both switches on the link. The word "auto" just makes us all want to think that the link would trunk automatically, but this command is both automatic and passive. As a result, both switches passively wait on the other device on the link to begin negotiations.

With this particular incorrect configuration, the **show interfaces switchport** command on both switches confirms both the administrative state (auto), as well as the fact that both switches operate as "static access" ports. Example 10-9 highlights those parts of the output from this command.

Example 10-9. Operational Trunking State

Click here to view code image

```
SW2# show interfaces gigabit0/2 switchport
Name: Gi0/2
Switchport: Enabled
Administrative Mode: dynamic auto
Operational Mode: static access
Administrative Trunking Encapsulation: dot1q
Operational Trunking Encapsulation: native
! lines omitted for brevity
```

A different incorrect trunking configuration results in one switch with an operational state of "trunk," while the other switch has an operational state of "static access." When this combination of events happens, the interface works a little. The status on each end will be up/up or connected. Traffic in the native VLAN will actually cross the link successfully. However, traffic in all the rest of the VLANs will not cross the link.

Figure 10-7 shows the incorrect configuration along with which side trunks and which does not. The side that trunks (SW1 in this case) enables trunking always, using the command **switchport mode trunk**. However, this command does not disable DTP negotiations. To cause this particular problem, SW1 also disables DTP negotiation using the **switchport nonegotiate** command. SW2's configuration also helps create the problem, by using a trunking option that relies on DTP. Because SW1 has disabled DTP, SW2's DTP negotiations fail, and SW2 does not trunk.

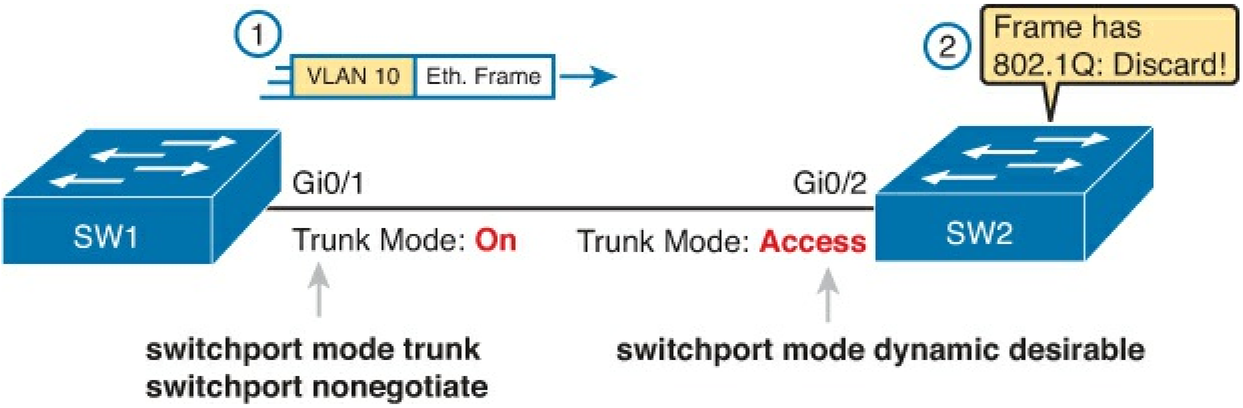


Figure 10-7. Mismatched Trunking Operational States

In this case, SW1 treats its G0/1 interface as a trunk, and SW2 treats its G0/2 interface as an access port (not a trunk). As shown in the figure at Step 1, SW1 could (for example) forward a frame in VLAN 10 (Step 1). However, SW2 would view any frame that arrives with an 802.1Q header as illegal, because SW2 treats its G0/2 port as an access port. So, SW2 discards any 802.1Q frames received on that port.

First, to deal with the possibility of this problem, always check the trunk's operational state on both sides of the trunk. The best commands to check trunking-related facts are **show interfaces trunk** and **show interfaces switchport**.

Note

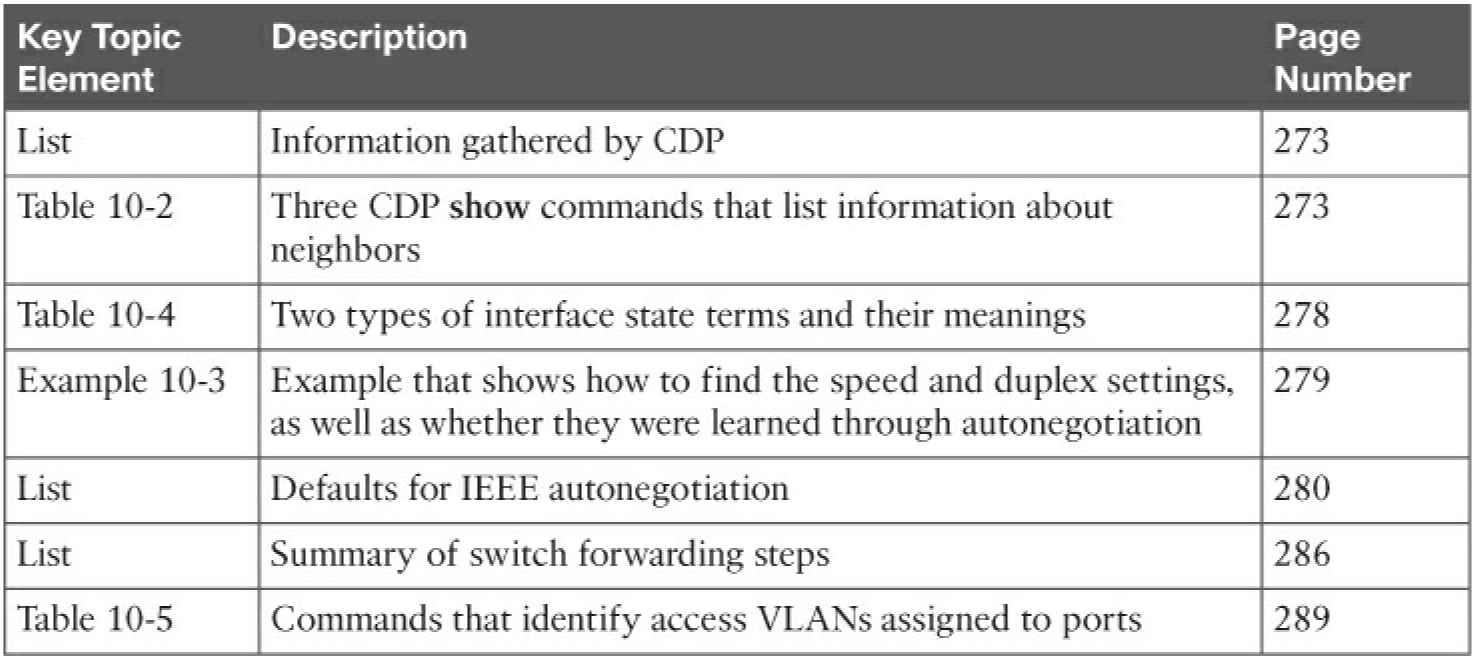
Frankly, in real life, just avoid this kind of configuration. However, the switches do not prevent you from making these types of mistakes, so you need to be ready.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 10-6 lists these key topics and where each is discussed.

Table 10-6. Key Topics for Chapter 10



Key Topic Element	Description	Page Number
List	Information gathered by CDP	273
Table 10-2	Three CDP **show** commands that list information about neighbors	273
Table 10-4	Two types of interface state terms and their meanings	278
Example 10-3	Example that shows how to find the speed and duplex settings, as well as whether they were learned through autonegotiation	279
List	Defaults for IEEE autonegotiation	280
List	Summary of switch forwarding steps	286
Table 10-5	Commands that identify access VLANs assigned to ports	289

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists for you to check your work.

Definitions of Key Terms

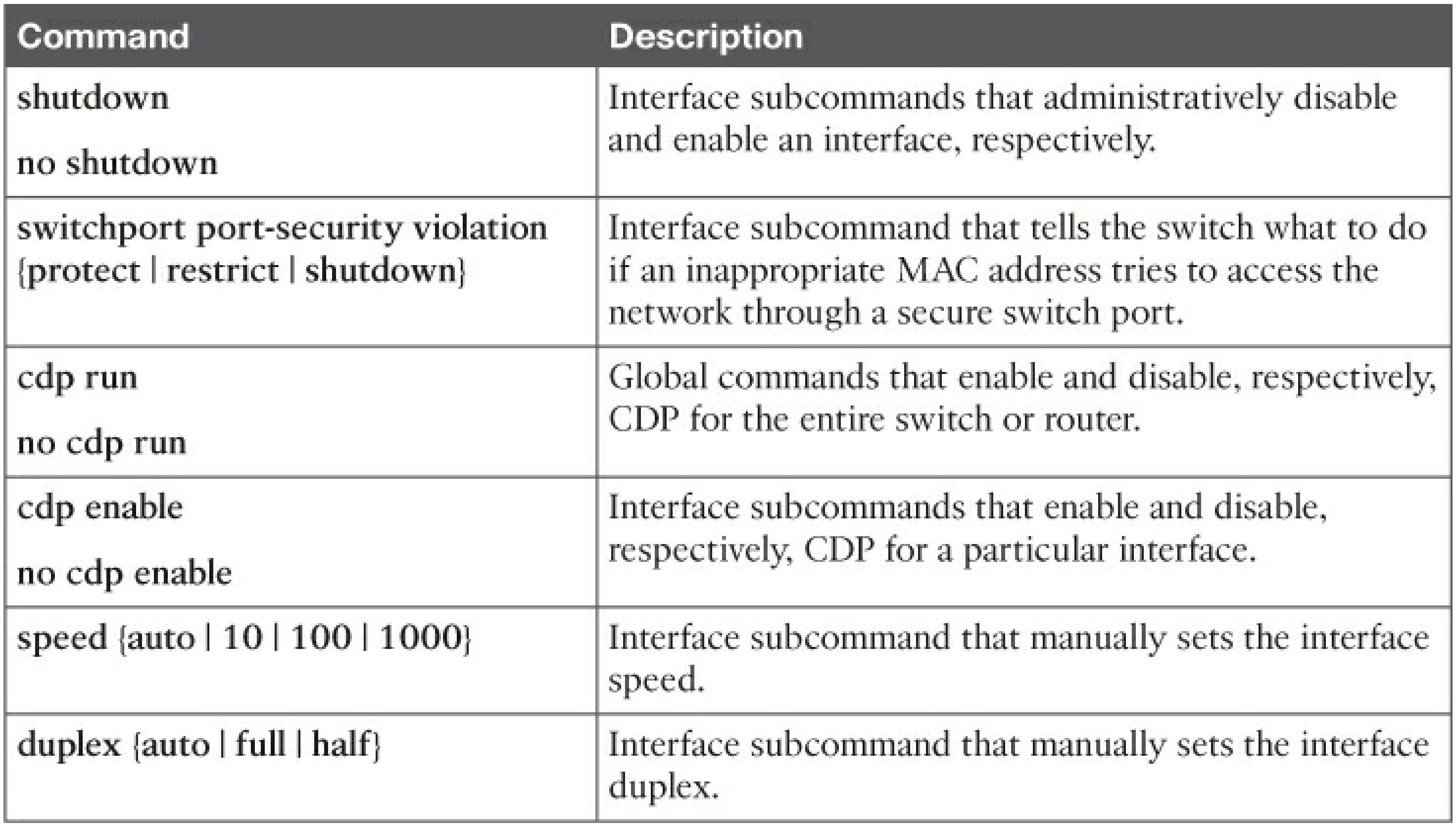
After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

CDP neighbor
up and up
connected
error disabled
problem isolation
root cause
duplex mismatch

Command References

Tables 10-7 and 10-8 list only commands specifically mentioned in this chapter, but the command references at the end of Chapters 8 and 9 also cover some related commands. Table 10-7 lists and briefly describes the configuration commands used in this chapter.

Table 10-7. Commands for Catalyst 2960 Switch Configuration



Command	Description
shutdown **no shutdown**	Interface subcommands that administratively disable and enable an interface, respectively.
switchport port-security violation {**protect** | **restrict** | **shutdown**}	Interface subcommand that tells the switch what to do if an inappropriate MAC address tries to access the network through a secure switch port.
cdp run **no cdp run**	Global commands that enable and disable, respectively, CDP for the entire switch or router.
cdp enable **no cdp enable**	Interface subcommands that enable and disable, respectively, CDP for a particular interface.
speed {**auto** | **10** | **100** | **1000**}	Interface subcommand that manually sets the interface speed.
duplex {**auto** | **full** | **half**}	Interface subcommand that manually sets the interface duplex.

Table 10-8 lists and briefly describes the EXEC commands used in this chapter.

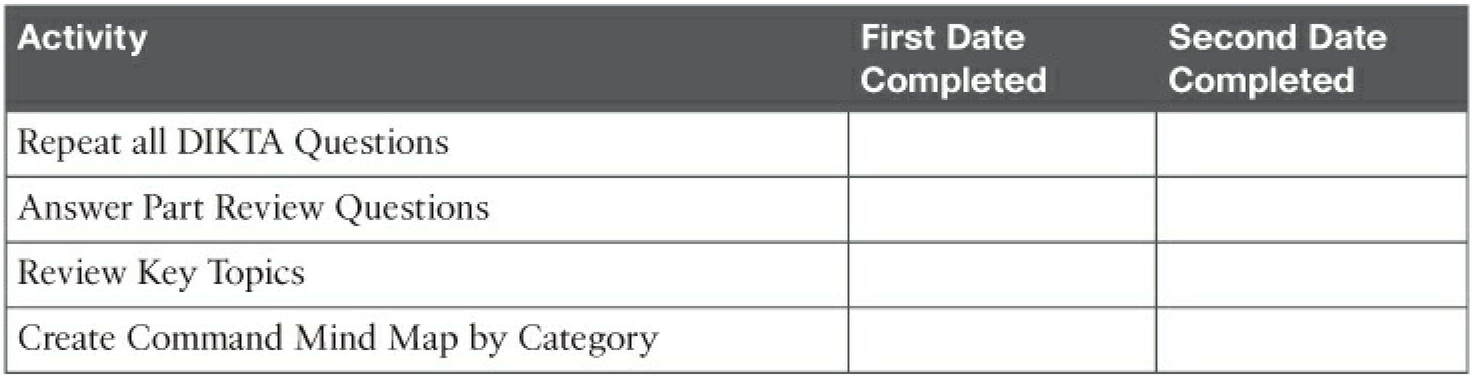
Table 10-8. Chapter 10 EXEC Command Reference

Command	Description
show mac address-table [**dynamic** | **static**] [**address** *hw-addr*] [**interface** *interface-id*] [**vlan** *vlan-id*]	Displays the MAC address table. The security option displays information about the restricted or static settings.
show port-security [**interface** *interface-id*] [**address**]	Displays information about security options configured on an interface.
show cdp neighbors [*type number*]	Lists one summary line of information about each neighbor, or just the neighbor found on a specific interface if an interface was listed.
show cdp neighbors detail	Lists one large set of information (approximately 15 lines) for every neighbor.
show cdp entry *name*	Displays the same information as the **show cdp neighbors detail** command, but only for the named neighbor.
show cdp	States whether CDP is enabled globally, and lists the default update and holdtime timers.
show cdp interface [*type number*]	States whether CDP is enabled on each interface, or
show interfaces [*type number*] **status**	Displays summary information about interface status and settings, including actual speed and duplex, a single-item status code, and whether the interface was autonegotiated.
show interfaces [*type number*] **switchport**	Displays a large variety of configuration settings and current operational status, including VLAN trunking details, access and voice VLAN, and native VLAN.
show interfaces [*type number*] **trunk**	Lists information about the currently operational trunks (or just for the trunk listed in the command) and the VLANs supported on those trunks.
show vlan brief, **show vlan**	Lists each VLAN and all interfaces assigned to that VLAN but does not include trunks.
show vlan id *num*	Lists both access and trunk ports in the VLAN.
show vtp status	Lists the current VTP status, including the current mode.

Part II Review

Keep track of your part review progress with the checklist shown in Table P2-1. Details on each task follow the table.

Table P2-1. Part II Part Review Checklist



Activity	First Date Completed	Second Date Completed
Repeat all DIKTA Questions		
Answer Part Review Questions		
Review Key Topics		
Create Command Mind Map by Category		

Repeat All DIKTA Questions

For this task, answer the "Do I Know This Already?" questions again for the chapters in this part of the book, using the PCPT software. Refer to the Introduction to this book, heading "How to View Only DIKTA Questions by Part," for help with how to make the PCPT software show you DIKTA questions for this part only.

Answer Part Review Questions

For this task, answer the Part Review questions for this part of the book, using the PCPT software. Refer to the Introduction to this book, heading "How to View Only Part Review Questions by Part," for help with how to make the PCPT software show you Part Review questions for this part only.

Review Key Topics

Key Topic

Browse back through the chapters, and look for the Key Topic icons. If you do not remember some details, take the time to reread those topics.

Create Command Mind Map by Category

Part II of this book both introduces the Cisco command-line interface (CLI) and introduces a large number of both configuration and EXEC commands. The sheer number of commands can be a bit overwhelming.

For the exam, you do not necessarily have to memorize every command and every parameter. However, you should be able to remember all the categories of topics that can be configured in LAN switches, and at least remember the first word or two of most of the commands. This mind map exercise is designed to help you work on organizing these commands in your mind.

Create a mind map with the following categories of commands from this part of the book:

> console and VTY, SSH, switch IPv4 support, port security, VLANs, VLAN trunks, CDP, other switch admin, other interface subcommands

For each category, think of all configuration commands and all EXEC commands (mostly **show** commands). For each category, group the configuration commands separately from the EXEC commands. Figure P2-1 shows a sample for the CDP branch of the commands.

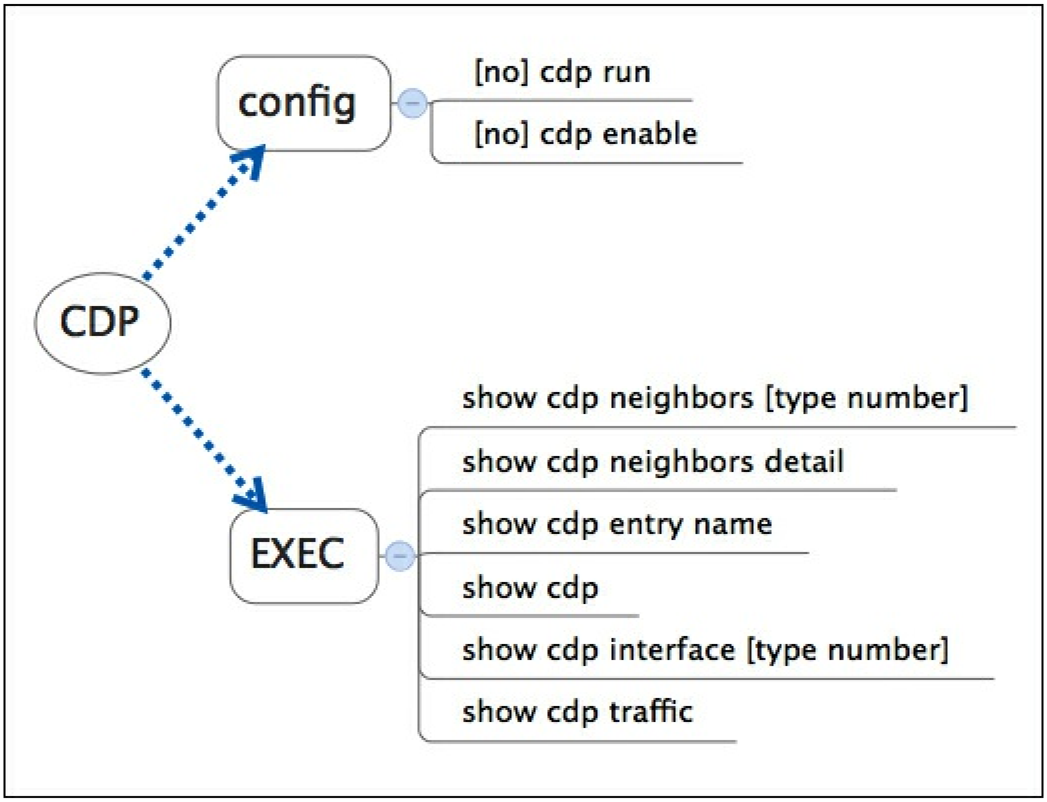

config
[no] cdp run
[no] cdp enable
CDP
EXEC
show cdp neighbors [type number]
show cdp neighbors detail
show cdp entry name
show cdp
show cdp interface [type number]
show cdp traffic

Figure P2-1. Sample Mind Map from the CDP Branch

Note

For more information on mind mapping, refer to the Introduction, in the section "About Mind Maps."

Finally, keep the following important points in mind when working on this project:

- Most of the learning with this exercise happens when you do it. Reading some other mind map, or just rereading command tables, does not work as well for helping you remember for yourself.
- Do this activity without notes and without looking at the book.
- After you finish, review it versus the command summary tables at the ends of the chapters, and note which commands you had originally forgotten.
- Do not worry about every last parameter or the exact syntax; just write down the first few words of the command.
- For later study, make a note about which commands you feel you truly understand and which ones about which you feel less confident.
- Repeat this exercise when you have ten spare minutes, as a way to see what you remember (again without your notes).

Appendix O, "Mind Map Solutions," lists a sample mind map answer, but as usual, your mind map can and will look different.

Part III: IP Version 4 Addressing and Subnetting

Parts III, IV, V, and VI all discuss features that make heavy use of IP version 4 (IPv4). This part focuses on the fundamentals of IPv4 addressing and subnetting. Chapter 11 takes a grand tour of IPv4 addressing as implemented inside a typical enterprise network. Chapters 12, 13, and 14 look at some of the specific questions people must ask themselves when operating an IPv4 network. Note that Part V also discusses other details related to IPv4 addressing.

Chapter 11: Perspectives on IPv4 Subnetting

Chapter 12: Analyzing Classful IPv4 Networks

Chapter 13: Analyzing Subnet Masks

Chapter 14: Analyzing Existing Subnets

Part III Review

Chapter 11. Perspectives on IPv4 Subnetting

This chapter covers the following exam topics:

IP addressing (IPv4/IPv6)

Describe the operation and necessity of using private and public IP addresses for IPv4 addressing

Identify the appropriate IPv4 addressing scheme using VLSM and summarization to satisfy addressing requirements in a LAN/WAN environment.

Most entry-level networking jobs require you to operate and troubleshoot a network using a preexisting IP addressing and subnetting plan. The CCENT and CCNA exams assess your readiness to use preexisting IP addressing and subnetting information to perform typical operations tasks, like monitoring the network, reacting to possible problems, and troubleshooting those problems.

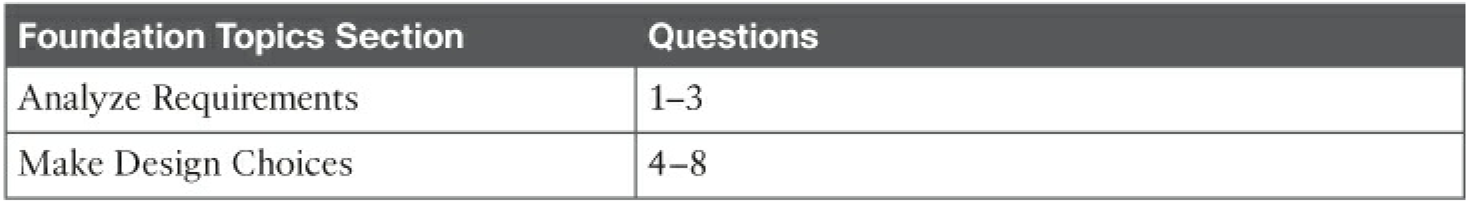
However, some exam questions, as well as many real-life issues at work, require that you understand the design of the network so that you can better operate the network. The process of monitoring any network requires that you continually answer the question, "Is the network working as *designed*?" If a problem exists, you must consider questions such as, "What happens when the network works normally, and what is different right now?" Both questions require you to understand the intended design of the network, including details of the IP addressing and subnetting design.

This chapter provides some perspectives and answers for the bigger issues in IPv4 addressing. What addresses can be used so that they work properly? What addresses should be used? When told to use certain numbers, what does that tell you about the choices made by some other network engineer? How do these choices impact the practical job of configuring switches, routers, hosts, and operating the network on a daily basis? This chapter hopes to answer these questions while revealing details of how IPv4 addresses work.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 11-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Analyze Requirements	1–3
Make Design Choices	4–8

1. Host A is a PC, connected to switch SW1 and assigned to VLAN 1. Which of the following are typically assigned an IP address in the same subnet as host A? (Select two answers)
   - **a.** The local router's WAN interface
   - **b.** The local router's LAN interface
   - **c.** All other hosts attached to the same switch
   - **d.** Other hosts attached to the same switch and also in VLAN 1
2. Why does the formula for the number of hosts per subnet ($2^H - 2$) require the subtraction of two hosts?
   - **a.** To reserve two addresses for redundant default gateways (routers)
   - **b.** To reserve the two addresses required for DHCP operation
   - **c.** To reserve addresses for the subnet ID and default gateway (router)
   - **d.** To reserve addresses for the subnet broadcast address and subnet ID
3. A Class B network needs to be subnetted such that it supports 100 subnets and 100 hosts/subnet. Which of the following answers list a workable combination for the number of network, subnet, and host bits? (Select two answers.)
   - **a.** Network = 16, subnet = 7, host = 7
   - **b.** Network = 16, subnet = 8, host = 8
   - **c.** Network = 16, subnet = 9, host = 7
   - **d.** Network = 8, subnet = 7, host = 17
4. Which of the following are private IP networks? (Select two answers.)
   - **a.** 172.31.0.0
   - **b.** 172.32.0.0
   - **c.** 192.168.255.0
   - **d.** 192.1.168.0
   - **e.** 11.0.0.0

5. Which of the following are public IP networks? (Select three answers.)
   - **a.** 9.0.0.0
   - **b.** 172.30.0.0
   - **c.** 192.168.255.0
   - **d.** 192.1.168.0
   - **e.** 1.0.0.0
6. Before Class B network 172.16.0.0 is subnetted by a network engineer, what parts of the structure of the IP addresses in this network already exist, with a specific size? (Select two answers.)
   - **a.** Network
   - **b.** Subnet
   - **c.** Host
   - **d.** Broadcast
7. A network engineer spends time thinking about the entire Class B network 172.16.0.0, and how to subnet that network. He then chooses how to subnet this Class B network and creates an addressing and subnetting plan, on paper, showing his choices. If you compare his thoughts about this network before subnetting the network, to his thoughts about this network after mentally subnetting the network, which of the following occurred to the parts of the structure of addresses in this network?
   - **a.** The subnet part got smaller.
   - **b.** The host part got smaller.
   - **c.** The network part got smaller.
   - **d.** The host part was removed.
   - **e.** The network part was removed.
8. Which of the following terms are *not* used to reference the one number in each subnet used to uniquely identify the subnet? (Select two answers.)
   - **a.** Subnet ID
   - **b.** Subnet number
   - **c.** Subnet broadcast
   - **d.** Subnet name
   - **e.** Subnet address

Answers to the "Do I Know This Already?" quiz:

1 A and D 2 D 3 B and C 4 A and C 5 A, D, and E 6 A and C 7 B 8 **C** and D

Foundation Topics

Introduction to Subnetting

Say you just happened to be at the sandwich shop when they were selling the world's longest sandwich. You're pretty hungry, so you go for it. Now you have one sandwich, but at over 2 kilometers long, you realize it's a bit more than you need for lunch all by yourself. To make the sandwich more useful (and more portable), you chop the sandwich into meal-size pieces, and give the pieces to other folks around you, who are also ready for lunch.

Huh? Well, subnetting, at least the main concept, is similar to this sandwich story. You start with one network, but it is just one large network. As a single large entity, it might not be useful, and it is probably far too large. To make it useful, you chop it into smaller pieces, called subnets, and assign those subnets to be used in different parts of the enterprise internetwork.

This short section introduces IP subnetting. First, it shows the general ideas behind a completed subnet design that indeed chops (or subnets) one network into subnets. The rest of this section describes the many design steps that you would take to create just such a subnet design. By the end of this section, you should have the right context to then read through the subnetting design steps introduced throughout the rest of this chapter.

Note

This chapter, and in fact the rest of the chapters in this book up until Chapter 25, "Fundamentals of IP Version 6," focuses on IPv4 rather than IPv6. All references to "IP" refer to IPv4 unless otherwise stated.

Subnetting Defined Through a Simple Example

An IP network—in other words, a Class A, B, or C network—is simply a set of consecutively numbered IP addresses that follows some preset rules. These Class A, B, and C rules, first introduced back in Chapter 4's section, "Class A, B, and C IP Networks," define that for a given network, all the addresses in the network have the same value in some of the octets of the addresses. For example, Class B network 172.16.0.0 consists of all IP addresses that begin with 172.16: 172.16.0.0, 172.16.0.1, 172.16.0.2, and so on, through 172.16.255.255. Another example: Class A network 10.0.0.0 includes all addresses that begin with 10.

An IP subnet is simply a subset of a Class A, B, or C network. If fact, the word *subnet* is a shortened version of the phrase *subdivided network*. For example, one subnet of Class B network 172.16.0.0 could be the set of all IP addresses that begin with 172.16.1 would include 172.16.1.0, 172.16.1.1, 172.16.1.2, and so on, up through 172.16.1.255. Another subnet of that same Class B network could be all addresses that begin 172.16.2.

To give you a general idea, Figure 11-1 shows some basic documentation from a completed subnet design that could be used when an engineer subnets Class B network 172.16.0.0.

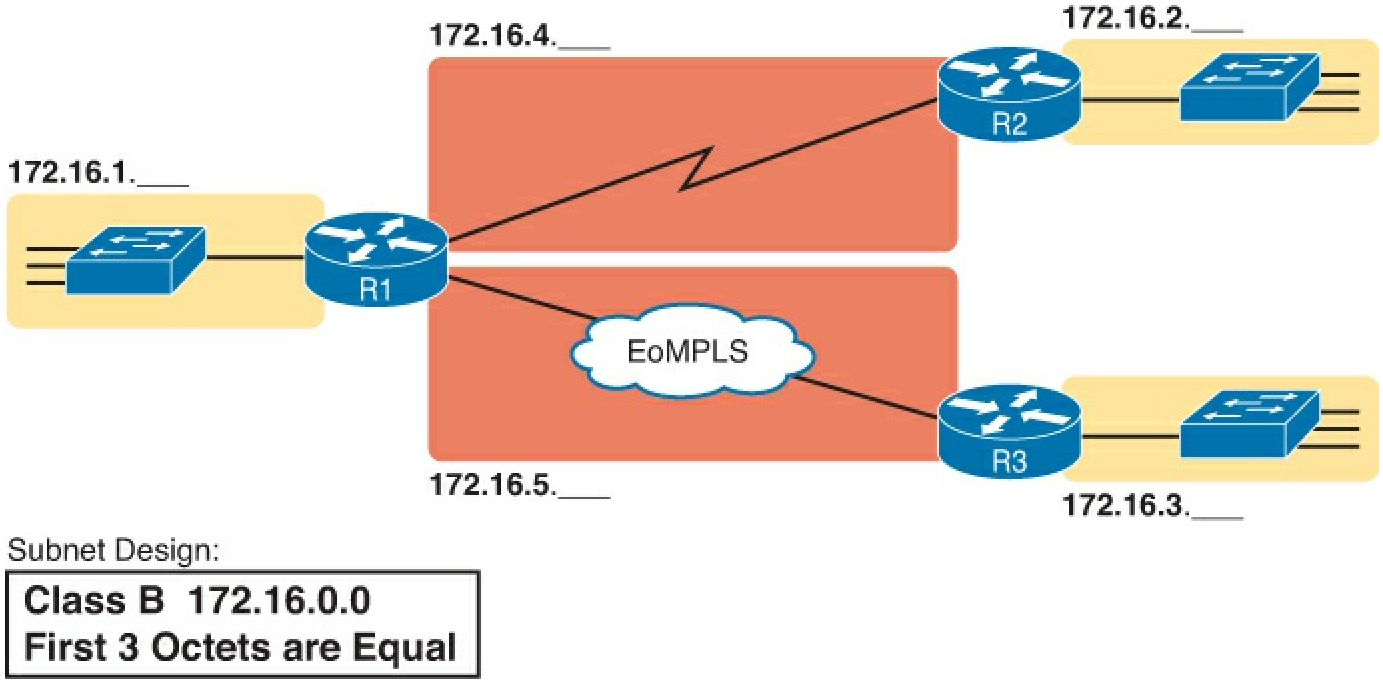


Figure 11-1. Example Subnet Plan Document

The design shows five subnets: one for each of the three LANs and one each for the two WAN links. The small text note shows the rationale used by the engineer for the subnets: Each subnet includes addresses that have the same value in the first three octets. For example, for the LAN on the left, the number shows 172.16.1.__, meaning "all addresses that begin with 172.16.1." Also, note that the design, as shown, does not use all the addresses in Class B network 172.16.0.0, so the engineer has left plenty of room for growth.

Operational View Versus Design View of Subnetting

Most IT jobs require you work with subnetting from an operational view. That is, someone else, before you got the job, designed how IP addressing and subnetting would work for that particular enterprise network. You need to interpret what someone else has already chosen.

To fully understand IP addressing and subnetting, you need to think about subnetting from both a design and operational perspective. For example, Figure 11-1 simply states that in all these subnets, the first three octets must be equal. Why was that convention chosen? What alternatives exist? Would those alternatives be better for your internetwork today? All these questions relate more to subnetting design rather than to operation.

To help you see both perspectives, some chapters in this part of the book focus more on design issues, while others focus more on operations by interpreting some existing design. This current chapter happens to move through the entire design process for the purpose of introducing the bigger picture of IP subnetting. Following this chapter, the rest of the chapters in this part of the book each take one topic from this chapter and examine it more closely, either from an operational or design perspective.

The remaining three main sections of this chapter examine each of the steps listed in Figure 11-2, in sequence.

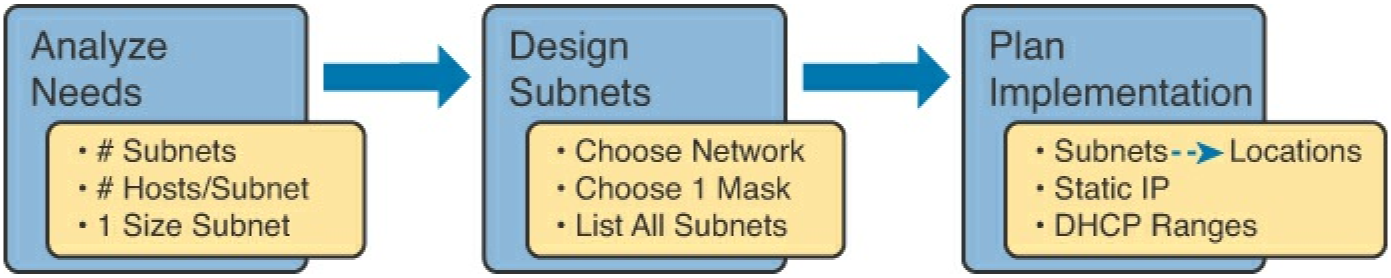


Figure 11-2. Subnet Planning, Design, and Implementation Tasks

> **Note**
>
> This chapter shows a subset of the functions included in the Cisco formal design process, called PPDIOO: Prepare, Plan, Design, Implement, Operate, and Optimize.

Analyze Subnetting and Addressing Needs

This section discusses the meaning of four basic questions that can be used to analyze the addressing and subnetting needs for any new or changing enterprise network:

1. Which hosts should be grouped together into a subnet?
2. How many subnets does this network require?
3. How many host IP addresses does each subnet require?
4. Will we use a single subnet size for simplicity, or not?

Rules About Which Hosts Are in Which Subnet

Every device that connects to an IP internetwork needs to have an IP address. These devices include computers used by end users, servers, mobile phones, laptops, IP phones, tablets, and networking devices like routers, switches, and firewalls. In short, any device that uses IP to send and receive packets needs an IP address.

> **Note**
>
> When discussing IP addressing, the term *network* has specific meaning: a Class A, B, or C IP network. To avoid confusion with that use of the term *network*, this book uses the terms *internetwork* and *enterprise network* when referring to a collection of hosts, routers, switches, and so on.

The IP addresses must be assigned according to some basic rules, and for good reasons. To make routing work efficiently, IP addressing rules group addresses into groups called subnets. The rules are as follows:

Key Topic

- Addresses in the same subnet are not separated by a router.
- Addresses in different subnets are separated by at least one router.

Figure 11-3 shows the general concept, with hosts A and B in one subnet and host C in another. In particular, note that hosts A and B are not separated from each other by any routers. However, host C, separated from A and B by at least one router, must be in a different subnet.

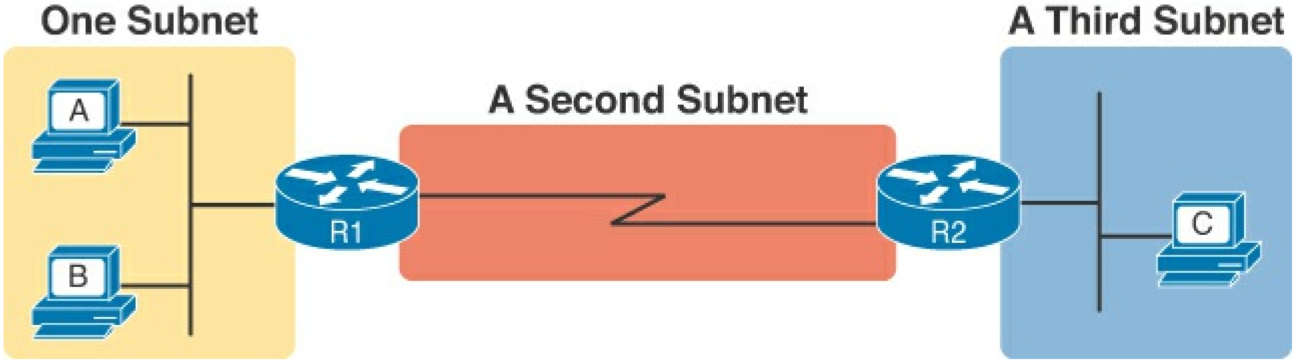


Figure 11-3. PC A and B in One Subnet, and PC C in a Different Subnet

The idea that hosts on the same link must be in the same subnet is much like the postal code concept. All mailing addresses in the same town use the same postal code (ZIP Codes in the United States). Addresses in another town, whether relatively nearby or on the other side of the country, have a different postal code. The postal code gives the postal service a better ability to automatically sort the mail to deliver it to the right location. For the same general reasons, hosts on the same LAN are in the same subnet, and hosts in different LANs are in different subnets.

Note that the point-to-point WAN link in the figure also needs a subnet. Figure 11-3 shows router R1 connected to the LAN subnet on the left and to a WAN subnet on the right. Router R2 connects to that same WAN subnet. To do so, both R1 and R2 will have IP addresses on their WAN interfaces, and the addresses will be in the same subnet. (An Ethernet over MPLS [EoMPLS] WAN link has the same IP addressing needs, with each of the two routers having an IP address in the same subnet.)

The Ethernet LANs in Figure 11-3 also show a slightly different style of drawing, using simple lines with no Ethernet switch. When drawing Ethernet LANs when the details of the LAN switches do not matter, drawings simply show each device connected to the same line, as seen in Figure 11-3. (This kind of drawing mimics the original Ethernet cabling before switches and hubs existed.)

Finally, because the routers' main job is to forward packets from one subnet to another, routers typically connect to multiple subnets. For example, in this case, router R1 connects to one LAN subnet on the left and one WAN subnet on the right. To do so, R1 will be configured with two different IP addresses, one per interface. These addresses will be in different subnets, because the interfaces connect the router to different subnets.

Determining the Number of Subnets

To determine the number of subnets required, the engineer must think about the internetwork as documented and apply the following rules. To do so, the engineer requires access to network diagrams, VLAN configuration details, and if you use Frame Relay WANs, details about the permanent virtual circuits (PVC). Based on this info, you should use these rules and plan for one subnet for every:

Key Topic

- VLAN
- Point-to-point serial link
- Ethernet emulation WAN link (EoMPLS)
- Frame Relay PVC

Note

WAN technologies like MPLS and Frame Relay allow subnetting options other than one subnet per pair of routers on the WAN, but this book only uses WAN technologies that have one subnet for each point-to-point WAN connection between two routers.

For example, imagine that the network planner has only Figure 11-4 on which to base the subnet design.

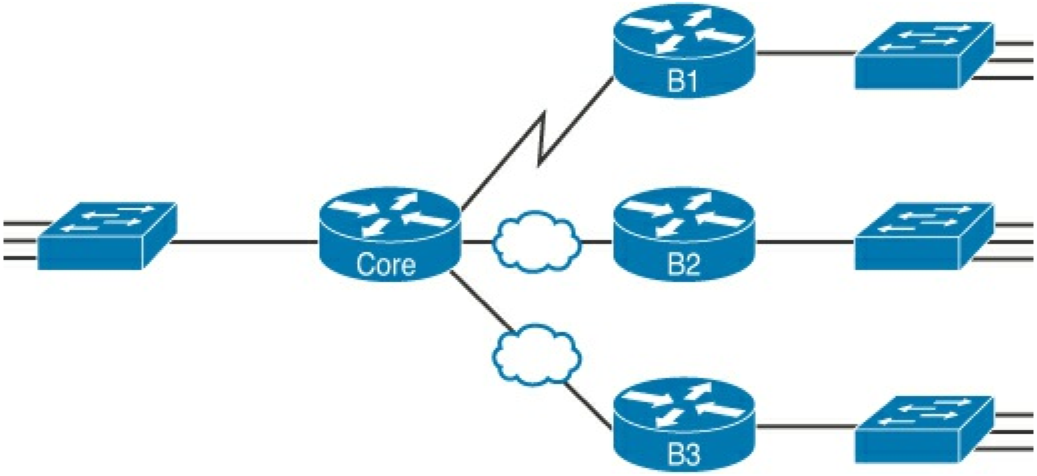


Figure 11-4. Four-Site Internetwork with Small Central Site

The number of subnets required cannot be fully predicted with only this figure. Certainly, three subnets will be needed for the WAN links, one per link. However, each LAN switch can be configured with a single VLAN, or with multiple VLANs. You can be certain that you need at least one subnet for the LAN at each site, but you might need more.

Next, consider the more detailed version of the same figure shown in Figure 11-5. In this case, the figure shows VLAN counts in addition to the same Layer 3 topology (the routers and the links connected to the routers). It also shows that the central site has many more switches, but the key fact on the left, regardless of how many switches exist, is that the central site has a total of 12 VLANs. Similarly, the figure lists each branch as having two VLANs. Along with the same three WAN subnets, this internetwork requires 21 subnets.

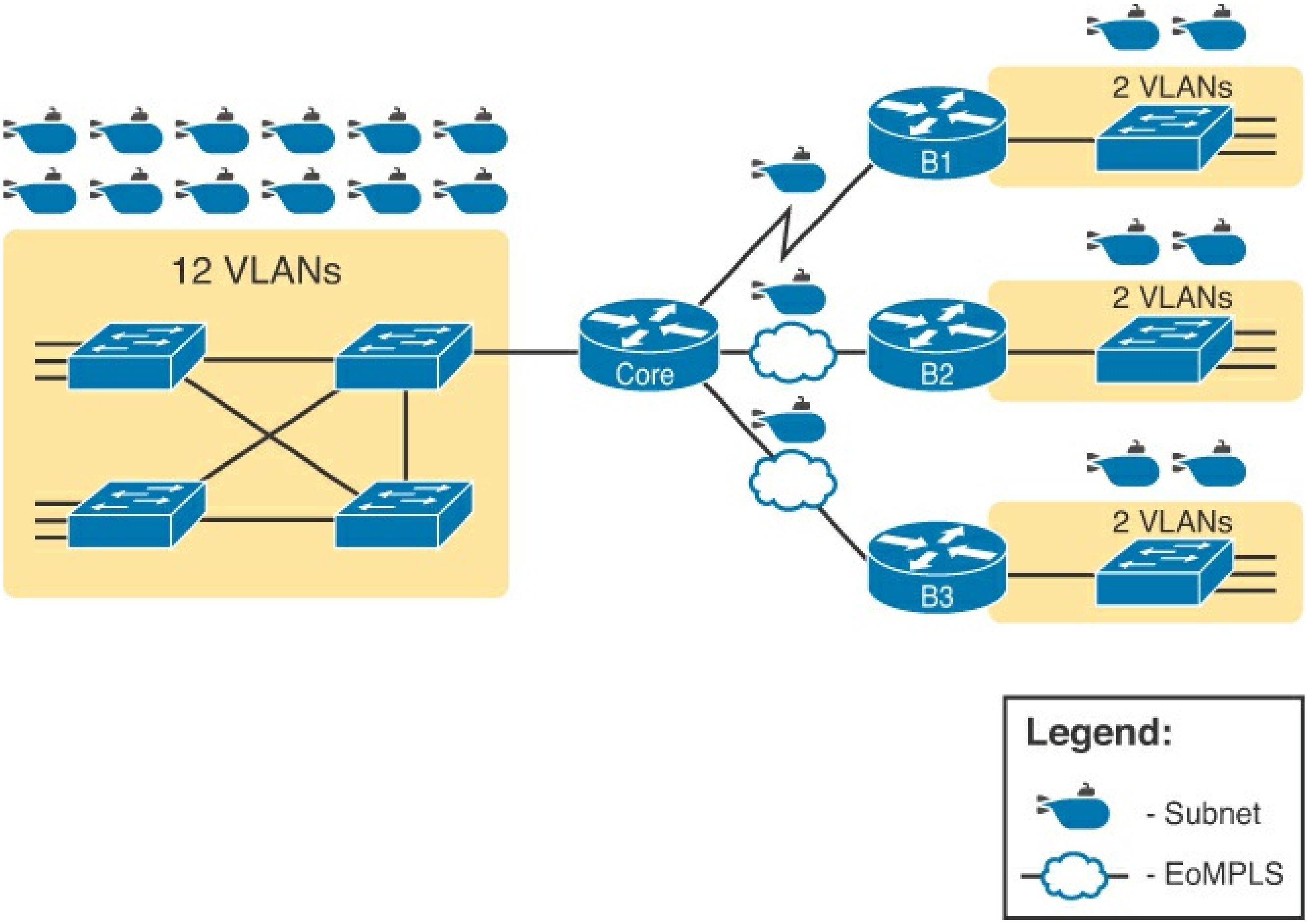


Figure 11-5. Four-Site Internetwork with Larger Central Site

Finally, in a real job, you would consider the needs today as well as how much growth you expect in the internetwork over time. Any subnetting plan should include a reasonable estimate of the number of subnets you need to meet future needs.

Determining the Number of Hosts per Subnet

Determining the number of hosts per subnet requires knowing a few simple concepts and then doing a lot of research and questioning. Every device that connects to a subnet needs an IP address. For a totally new network, you can look at business plans—numbers of people at the site, devices on order, and so on—to get some idea of the possible devices. When expanding an existing network to add new sites, you can use existing sites as a point of comparison, and then find out which sites will get bigger or smaller. And don't forget to count the router interface IP address in each subnet and the switch IP address used to remotely manage the switch.

Instead of gathering data for each and every site, planners often just use a few typical sites for planning purposes. For example, maybe you have some large sales offices and some small sales offices. You might dig in and learn a lot about only one large sales office and only one small sales office. Add that analysis to the fact that point-to-point links need a subnet with just two addresses, plus any analysis of more one-of-a-kind subnets, and you have enough information to plan the addressing and subnetting design.

For example, in Figure 11-6, the engineer has built a diagram that shows the number of hosts per LAN subnet in the largest branch, B1. For the two other branches, the engineer did not bother to dig to find out the number of required hosts. As long as the number of required IP addresses at sites B2 and B3 stays below the estimate of 50, based on larger site B1, the engineer can plan for 50 hosts in each branch LAN subnet and have plenty of addresses per subnet.

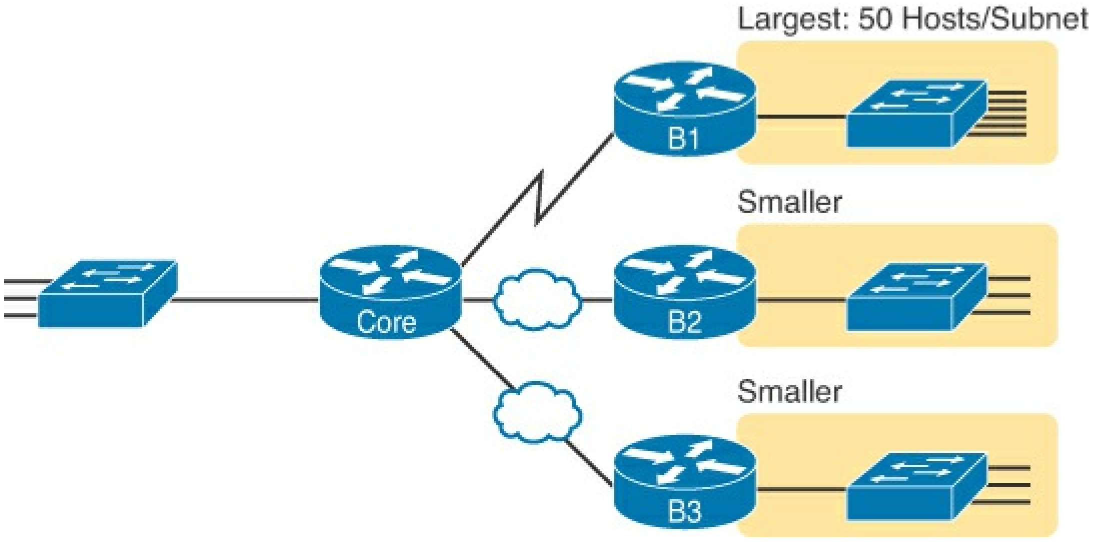


Figure 11-6. Large Branch B1 with 50 Hosts/Subnet

One Size Subnet Fits All—Or Not

The final choice in the initial planning step is to decide whether you will use a simpler design by using a one-size-subnet-fits-all philosophy. A subnet's size, or length, is simply the number of usable IP addresses in the subnet. A subnetting design can either use one size subnet, or varied sizes of subnets, with pros and cons for each choice.

Defining the Size of a Subnet

Before you finish this book, you will learn all the details of how to determine the size of the subnet. For now, you just need to know a few specific facts about the size of subnets. Chapter 12, "Analyzing Classful IPv4 Networks," and Chapter 13, "Analyzing Subnet Masks," give you a progressively deeper knowledge of the details.

The engineer assigns each subnet a *subnet mask*, and that mask, among other things, defines the size of that subnet. The mask sets aside a number of *host bits* whose purpose is to number different host IP addresses in that subnet. Because you can number 2^x things with x bits, if the mask defines H host bits, the subnet contains 2^H unique numeric values.

However, the subnet's size is not 2^H. It's $2^H - 2$, because two numbers in each subnet are reserved for other purposes. Each subnet reserves the numerically lowest value for the *subnet number* and the numerically highest value as the *subnet broadcast address*. As a result, the number of usable IP addresses per subnet is $2^H - 2$.

> **Note**
>
> The terms *subnet number*, *subnet ID*, and *subnet address* all refer to the number that represents or identifies a subnet.

Figure 11-7 shows the general concept behind the three-part structure of an IP address, focusing on the host part and the resulting subnet size.

Key Topic

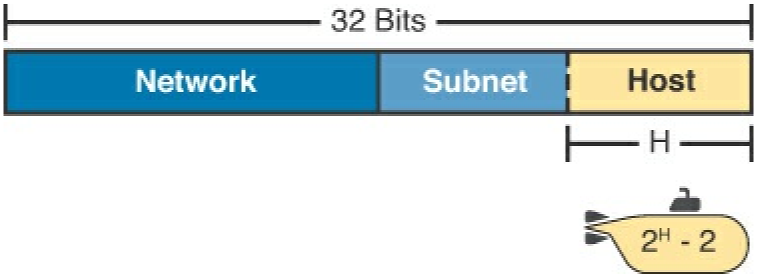


Figure 11-7. Subnet Size Concepts

One Size Subnet Fits All

To choose to use a single-size subnet in an enterprise network, you must use the same mask for all subnets, because the mask defines the size of the subnet. But which mask?

One requirement to consider when choosing that one mask is this: That one mask must provide enough host IP addresses to support the largest subnet. To do so, the number of host bits (H) defined by the mask must be large enough so that $2^H - 2$ is larger than (or equal to) the number of host IP addresses required in the largest subnet.

For example, consider Figure 11-8. It shows the required number of hosts per LAN subnet. (The figure ignores the subnets on the WAN links, which require only two IP addresses each.) The branch LAN subnets require only 50 host addresses, but the main site LAN subnet requires 200 host addresses. To accommodate the largest subnet, you need at least 8 host bits. Seven host bits would not be enough, because $2^7 - 2 = 126$. Eight host bits would be enough, because $2^8 - 2 = 254$, which is more than enough to support 200 hosts in a subnet.

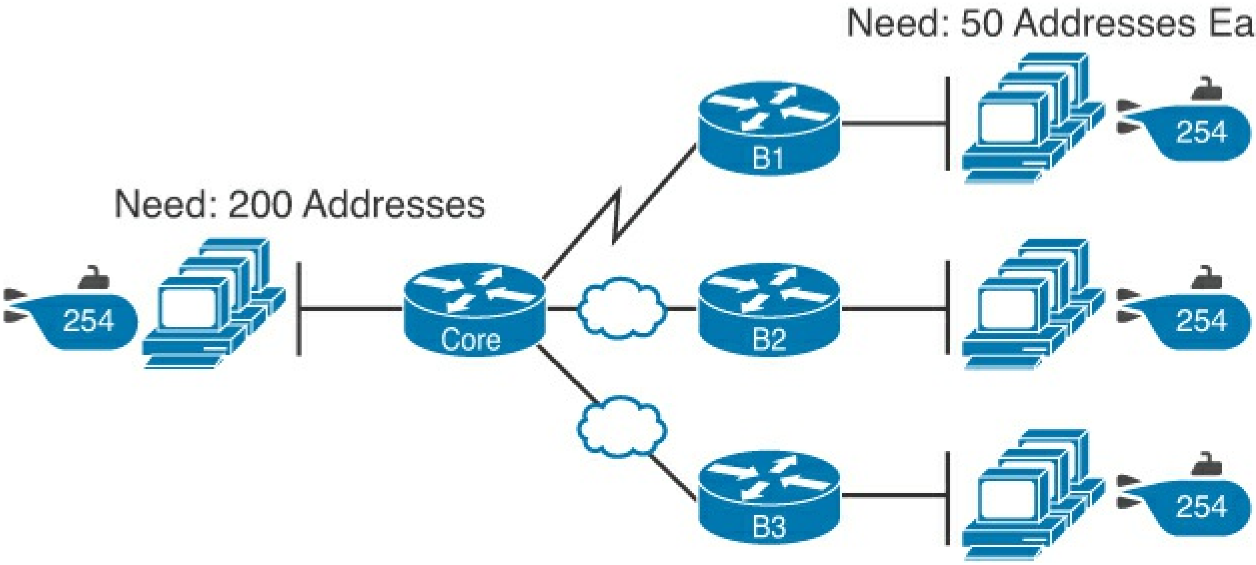


Figure 11-8. Network Using One Subnet Size

What's the big advantage when using a single-size subnet? Operational simplicity. In other words, keeping it simple. Everyone on the IT staff who has to work with networking can get used to working with one mask—and one mask only. They will be able to answer all subnetting questions more easily, because everyone gets used to doing subnetting math with that one mask.

The big disadvantage for using a single-size subnet is that it wastes IP addresses. For example, in Figure 11-8, all the branch LAN subnets support 254 addresses, while the largest branch subnet needs only 50 addresses. The WAN subnets only need two IP addresses, but each supports 254 addresses, again wasting more IP addresses.

The wasted IP addresses do not actually cause a problem in most cases, however. Most organizations use private IP networks in their enterprise internetworks, and a single Class A or Class B private network can supply plenty of IP addresses, even with the waste.

Multiple Subnet Sizes (Variable-Length Subnet Masks)

To create multiple sizes of subnets in one Class A, B, or C network, the engineer must create some subnets using one mask, some with another, and so on. Different masks mean different numbers of host bits, and a different number of hosts in some subnets based on the $2^H - 2$ formula.

For example, consider the requirements listed earlier in Figure 11-8. It showed one LAN subnet on the left that needs 200 host addresses, three branch subnets that need 50 addresses, and three WAN links that need two addresses. To meet those needs, but waste fewer IP addresses, three subnet masks could be used, creating subnets of three different sizes, as shown in Figure 11-9.

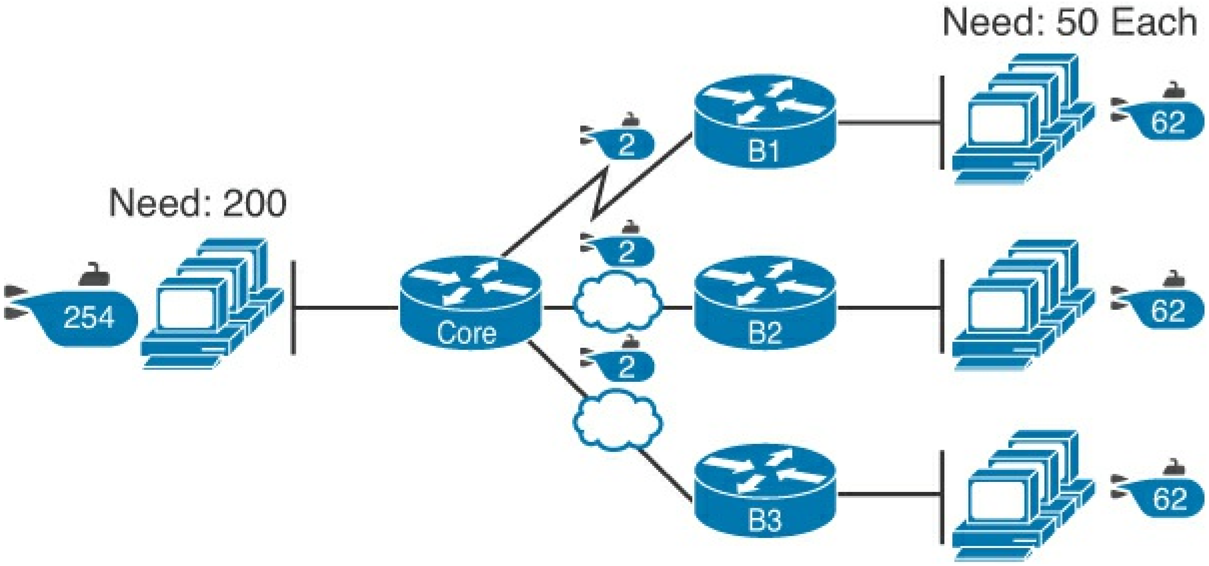


Figure 11-9. Three Masks, Three Subnet Sizes

The smaller subnets now waste fewer IP addresses compared to the design seen earlier in Figure 11-8. The subnets on the right that need 50 IP addresses have subnets with 6 host bits, for $2^6 - 2 = 62$ available addresses per subnet. The WAN links use masks with 2 host bits, for $2^2 - 2 = 2$ available addresses per subnet.

However, some are still wasted, because you cannot set the size of the subnet as some arbitrary size. All subnets will be a size based on the $2^H - 2$ formula, with H being the number of host bits defined by the mask for each subnet.

This Book: One Size Subnet Fits All (Mostly)

For the most part, this book explains subnetting using designs that use a single mask, creating a single subnet size for all subnets. Why? First, it makes the process of learning subnetting easier. Second, some types of analysis that you can do about a network—specifically, calculating the number of subnets in the classful network—only make sense when a single mask is used.

However, you still need to be ready to work with *variable-length subnet masks (VLSM)*, which is the practice of using different masks for different subnets in the same classful IP network. All of Chapter 20 focuses on VLSM, with Chapter 21, "Route Summarization," also using some math principles from VLSM. However, all the examples and discussion up until those chapters purposefully avoid VLSM just to keep the discussion simpler, for the sake of learning to walk before you run.

Make Design Choices

Now that you know how to analyze the IP addressing and subnetting needs, the next major step examines how to apply the rules of IP addressing and subnetting to those needs and mask some choices. In other words, now that you know how many subnets you need and how many host addresses you need in the largest subnet, how do you create a useful subnetting design that meets those requirements? The short answer is that you need to do the three tasks shown on the right side of Figure 11-10.

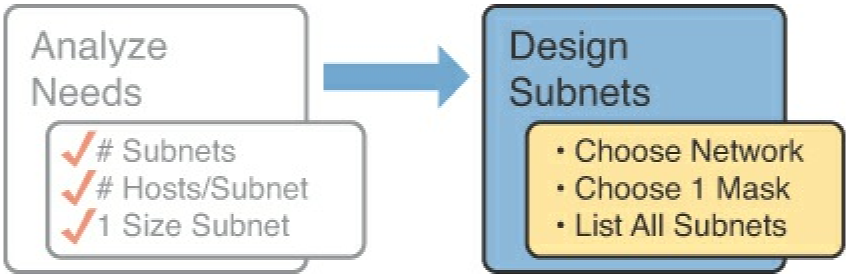


Figure 11-10. Input to the Design Phase, and Design Questions to Answer

Choose a Classful Network

In the original design for what we know of today as the Internet, companies used registered *public classful IP networks* when implementing TCP/IP inside the company. By the mid 1990s, an alternative became more popular: *private IP networks*. This section discusses the background behind these two choices, because it impacts the choice of what IP network a company will then subnet and implement in its enterprise internetwork.

Public IP Networks

The original design of the Internet required that any company that connected to the Internet had to use a *registered public IP network*. To do so, the company would complete some paperwork, describing the enterprise's internetwork and the number of hosts existing, plus plans for growth. After submitting the paperwork, the company would receive an assignment of either a Class A, B, or C network.

Public IP networks, and the administrative processes surrounding them, ensure that all the companies that connect to the Internet all use unique IP addresses. In particular, after a public IP network is assigned to a company, only that company should use the addresses in that network. That guarantee of uniqueness means that Internet routing can work well, because there are no duplicate public IP addresses.

For example, consider the example shown in Figure 11-11. Company 1 has been assigned public Class A network 1.0.0.0, and company 2 has been assigned public Class A network 2.0.0.0. Per the original intent for public addressing in the Internet, after these public network assignments have been made, no other companies can use addresses in Class A networks 1.0.0.0 or 2.0.0.0.

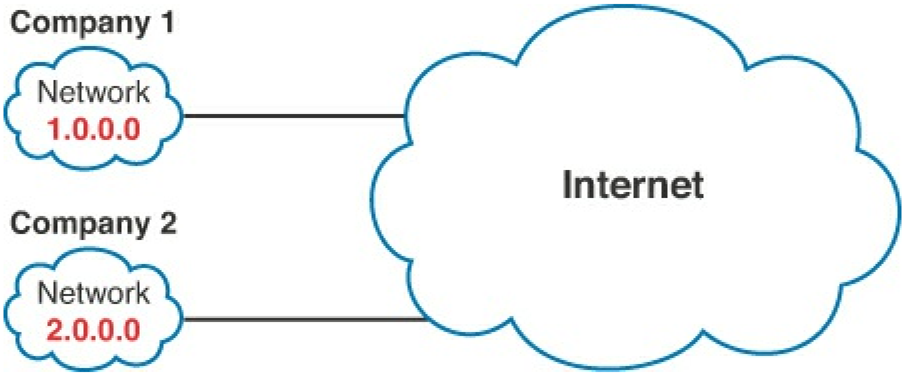


Figure 11-11. Two Companies with Unique Public IP Networks

This original address assignment process ensured unique IP addresses across the entire planet. The idea is much like the fact that your telephone number should be unique in the universe, your postal mailing address should also be unique, and your email address should also be unique. If someone calls you, your phone rings, but no one else's phone rings. Similarly, if company 1 is assigned Class A network 1.0.0.0, and it assigns address 1.1.1.1 to a particular PC, that address should be unique in the universe. A packet sent through the Internet, to destination 1.1.1.1, should only arrive at this one PC inside company 1, instead of being delivered to some other host.

Growth Exhausts the Public IP Address Space

By the early 1990s, the world was running out of public IP networks that could be assigned. During most of the 1990s, the number of hosts newly connected to the Internet was growing at a double-digit pace, *per month*. Companies kept following the rules, asking for public IP networks, and it was clear that the current address-assignment scheme could not continue without some changes. Simply put, the number of Class A, B, and C networks supported by the 32-bit address in IP version 4 (IPv4) was not enough to support one public classful network per organization, while also providing enough IP addresses in each company.

Note

From one perspective, the universe ran out of public IPv4 addresses in early 2011. IANA, which assigns public IPv4 address blocks to the five Internet registries around the globe, assigned the last of the IPv4 address space in early 2011.

The Internet community worked hard during the 1990s to solve this problem, coming up with several solutions, including the following:

Key Topic

- A new version of IP (IPv6), with much larger addresses (128 bit)
- Assigning a subset of a public IP network to each company, instead of an entire public IP network, to reduce waste
- Network Address Translation (NAT), which allows the use of private IP networks

These three solutions matter to real networks today. However, to stay focused on the topic of subnet design, this chapter focuses on the third option, and in particular, the private IP networks that can be used by an enterprise when also using NAT.

NAT, which is detailed in Chapter 24, "Network Address Translation," allows multiple companies to use the exact same *private IP network*, using the same IP addresses as other companies, while still connecting to the Internet. For example, Figure 11-12 shows the same two companies connecting to the Internet as in Figure 11-11, but now with both using the same private Class A network 10.0.0.0.

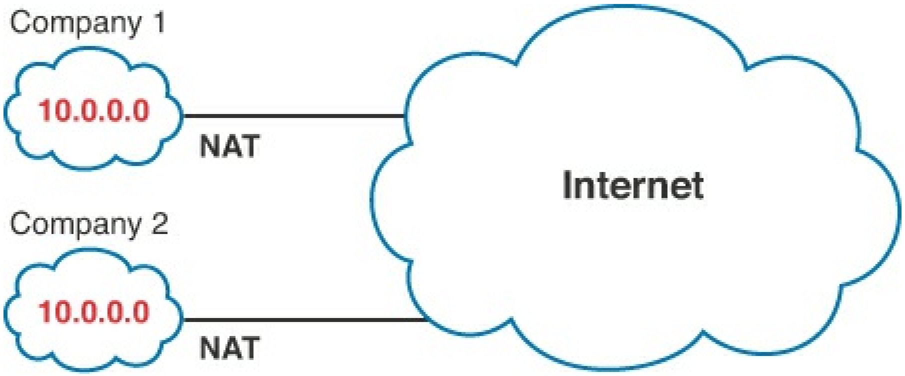


Figure 11-12. Reusing the Same Private Network 10.0.0.0, with NAT

Both companies use the same classful IP network (10.0.0.0). Both companies can implement their subnet design internal to their respective enterprise internetworks, without discussing their plans. The two companies can even using the exact same IP addresses inside network 10.0.0.0. And amazingly, at the same time, both companies can even communicate with each other through the Internet.

The technology called Network Address Translation (NAT) makes it possible for companies to reuse the same IP networks, as shown in Figure 11-12. NAT does this by translating the IP addresses inside the packets as they go from the enterprise to the Internet, using a small number of public IP addresses to support tens of thousands of private IP addresses. That one bit of information is not enough to understand how NAT works; however, to keep the focus on subnetting, the book defers the discussion of how NAT works until Chapter 24. For now, accept that most companies use NAT, and therefore, they can use private IP networks for their internetworks.

Private IP Networks

RFC 1918 defines the set of private IP networks, as listed in Table 11-2. By definition, these private IP networks

- Will never be assigned to an organization as a public IP network
- Can be used by organizations that will use NAT when sending packets into the Internet
- Can also be used by organizations that never need to send packets into the Internet

Table 11-2. RFC 1918 Private Address Space

Class of Networks	Private IP Networks	Number of Networks
A	10.0.0.0	1
B	172.16.0.0 through 172.31.0.0	16
C	192.168.0.0 through 192.168.255.0	256

So, when using NAT—and almost every organization that connects to the Internet uses NAT—the company can simply pick one or more of the private IP networks from the list of reserved private IP network numbers. RFC 1918 defines the list, which is summarized in Table 11-2.

> **Note**
>
> According to an informal survey I ran in my blog back in late 2010, about half of the respondents said that their networks use private Class A network 10.0.0.0, as opposed to other private networks or public networks.

Choosing an IP Network During the Design Phase

Today, some organizations use private IP networks along with NAT, and some use public IP networks. Most new enterprise internetworks use private IP addresses throughout the network, along with NAT, as part of the connection to the Internet. Those organizations that already have a registered public IP networks—often obtained before the addresses started running short in the early 1990s—can continue to use those public addresses throughout their enterprise networks.

After the choice to use a private IP network has been made, just pick one that has enough IP addresses. You can have a small internetwork and still choose to use private Class A network 10.0.0.0. It might seem wasteful to choose a Class A network that has over 16 million IP addresses, especially if you only need a few hundred. However, there’s no penalty or problem with using a private network that is too large for your current or future needs.

For the purposes of this book, most examples use private IP network numbers. For the design step to choose a network number, just choose a private Class A, B, or C network from the list of RFC 1918 private networks.

Regardless, from a math and concept perspective, the methods to subnet a public IP network versus a private IP network are the same.

Choose the Mask

If a design engineer followed the topics in this chapter so far, in order, he would know the following:

- The number of subnets required
- The number of hosts/subnet required
- That a choice was made to use only one mask for all subnets, so that all subnets are the same size (same number of hosts/subnet)
- The classful IP network number that will be subnetted

This section completes the design process, at least the parts described in this chapter, by discussing how to choose that one mask to use for all subnets. First, this section examines default masks, used when a network is not subnetted, as a point of comparison. Next, the concept of borrowing host bits to create subnet bits is explored. Finally, this section ends with an example of how to create a subnet mask based on the analysis of the requirements.

Classful IP Networks Before Subnetting

Before an engineer subnets a classful network, the network is a single group of addresses. In other words, the engineer has not yet subdivided the network into many smaller subsets called *subnets*.

When thinking about an unsubnetted classful network, the addresses in a network have only two parts: the network part and host part. Comparing any two addresses in the classful network:

- The addresses have the same value in the network part.
- The addresses have different values in the host part.

The actual sizes of the network and host part of the addresses in a network can be easily predicted, as shown in Figure 11-13.

Key Topic

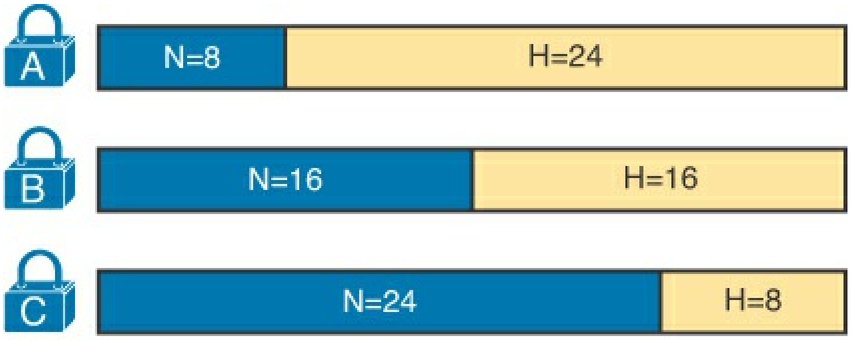


Figure 11-13. Format of Unsubnetted Class A, B, and C Networks

In Figure 11-13, N and H represent the number of network and host bits, respectively. Class rules define the number of network octets (1, 2, or 3) for Classes A, B, and C, respectively; the figure shows these values as a number of bits. The number of host octets is 3, 2, or 1, respectively.

Continuing the analysis of classful network before subnetting, the number of addresses in one classful IP network can be calculated with the same $2^{H} - 2$ formula previously discussed. In particular, the size of an unsubnetted Class A, B, or C network is as follows:

- **Class A:** $2^{24} - 2 = 16,777,214$
- **Class B:** $2^{16} - 2 = 65,534$
- **Class C:** $2^{8} - 2 = 254$

Borrowing Host Bits to Create Subnet Bits

To subnet a network, the designer thinks about the network and host parts, as shown in Figure 11-13, and then the engineer adds a third part in the middle: the subnet part. However, the designer cannot change the size of the network part or the size of the entire address (32 bits). To create a subnet part of the address structure, the engineer borrows bits from the host part. Figure 11-14 shows the general idea.

Key Topic

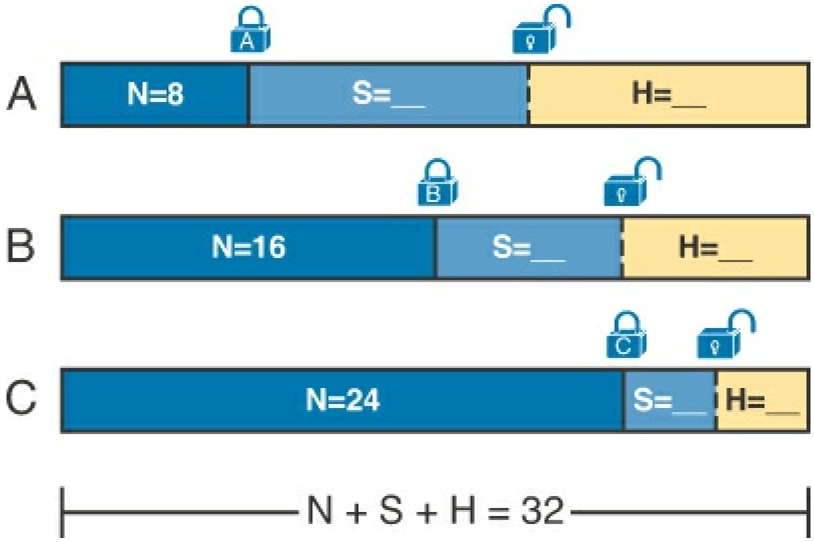


Figure 11-14. Concept of Borrowing Host Bits

Figure 11-14 shows a rectangle that represents the subnet mask. N, representing the number of network bits, remains locked at 8, 16, or 24, depending on the class. Conceptually, the designer moves a (dashed) dividing line into the host field, with subnet bits (S) between the network and host parts, and the remaining host bits (H) on the right. The three parts must add up to 32, because IPv4 addresses consist of 32 bits.

Choosing Enough Subnet and Host Bits

The design process requires a choice of where to place the dashed line shown in Figure 11-14. But what is the right choice? How many subnet and host bits should the designer choose? The answers hinge on the requirements gathered in the early stages of the planning process:

- Number of subnets required
- Number of hosts/subnet

The bits in the subnet part create a way to uniquely number the different subnets that the design engineer wants to create. With 1 subnet bit, you can number 2^1 or 2 subnets. With 2 bits, 2^2 or 4 subnets, with 3 bits, 2^3 or 8 subnets, and so on. The number of subnet bits must be large enough to uniquely number all the subnets, as determined during the planning process.

At the same time, the remaining number of host bits must also be large enough to number the host IP addresses in the largest subnet. Remember, in this chapter, we assume the use of a single mask for all subnets. This single mask must support both the required number of subnets and the required number of hosts in the largest subnet. Figure 11-15 shows the concept.

Key Topic

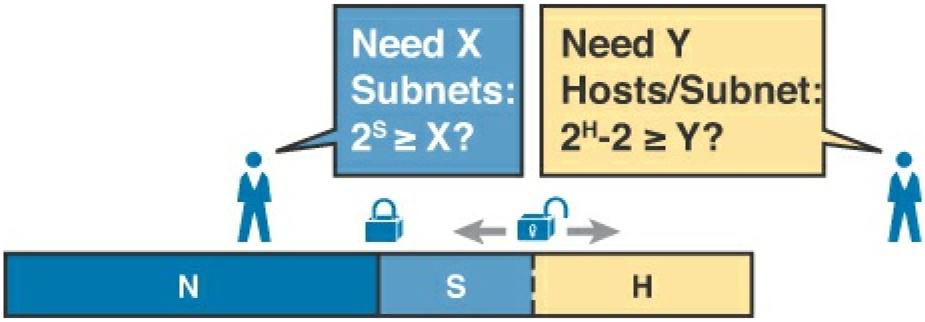

Need X Subnets: $2^S \geq X$?
Need Y Hosts/Subnet: $2^H-2 \geq Y$?
N
S
H

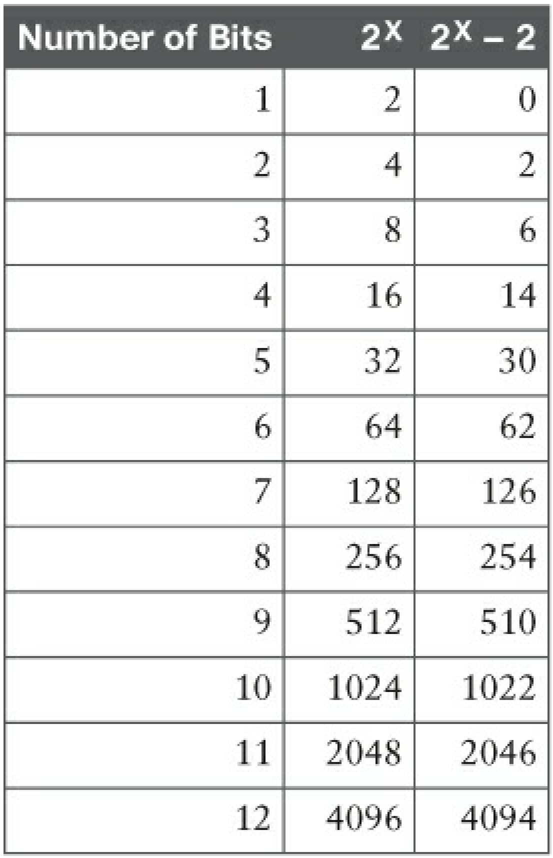
Figure 11-15. Borrowing Enough Subnet and Host Bits

Figure 11-15 shows the idea of the designer choosing a number of subnet (S) and host (H) bits and then checking the math. 2^S must be more than the number of required subnets, or the mask will not supply enough subnets in this IP network. Also, $2^H - 2$ must be more than the required number of hosts/subnet.

> **Note**
>
> The idea of calculating the number of subnets as 2^S applies only in cases where a single mask is used for all subnets of a single classful network, as is being assumed in this chapter.

To effectively design masks, or to interpret masks that were chosen by someone else, you need a good working memory of the powers of 2. Table 11-3 lists the powers of 2 up through 2^{12}, along with a column with $2^H - 2$, for perspective when calculating the number of hosts/subnet. Appendix A, "Numeric Reference Tables," lists a table with powers of 2 up through 2^{24} for your reference.

Table 11-3. Powers of 2 Reference for Designing Masks



Number of Bits	2^X	$2^X - 2$
1	2	0
2	4	2
3	8	6
4	16	14
5	32	30
6	64	62
7	128	126
8	256	254
9	512	510
10	1024	1022
11	2048	2046
12	4096	4094

Example Design: 172.16.0.0, 200 Subnets, 200 Hosts

To help make sense of the theoretical discussion so far, consider an example that focuses on the design choice for the subnet mask. In this case, the planning and design choices so far tell us the following:

- Use a single mask for all subnets.
- Plan for 200 subnets.
- Plan for 200 host IP addresses per subnet.
- Use private Class B network 172.16.0.0.

To choose the mask, the designer asks this question:

> How many subnet (S) bits do I need to number 200 subnets?

From Table 11-3, you can see that S = 7 is not large enough ($2^7 = 128$), but S = 8 is enough ($2^8 = 256$). So, you need *at least* 8 subnet bits.

Next, the designer asks a similar question, based on the number of hosts per subnet:

> How many host (H) bits do I need to number 200 hosts per subnet?

The math is basically the same, but the formula subtracts 2 when counting the number of hosts/subnet. From Table 11-3, you can see that H = 7 is not large enough ($2^7 - 2 = 126$), but H = 8 is enough ($2^8 - 2 = 254$).

Only one possible mask meets all the requirements in this case. First, the number of network bits (N) must be 16, because the design uses a Class B network. The requirements tell us that the mask needs at least 8 subnet bits, and at least 8 host bits. The mask only has 32 bits in it; Figure 11-16 shows the resulting mask.

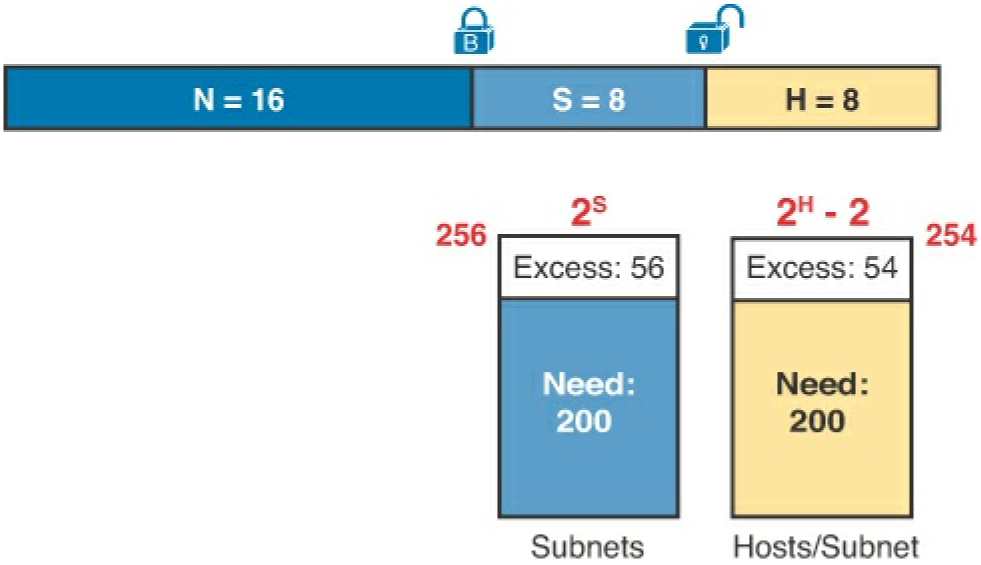


Figure 11-16. Example Mask Choice, N = 16, S = 8, H = 8

Masks and Mask Formats

Although engineers think about IP addresses in three parts when making design choices (network, subnet, and host), the subnet mask gives the engineer a way to communicate those design choices to all the devices in the subnet.

The subnet mask is a 32-bit binary number with a number of binary 1s on the left and with binary 0s on the right. By definition, the number of binary 0s equals the number of host bits—in fact, that is exactly how the mask communicates the idea of the size of the host part of the addresses in a subnet. The beginning bits in the mask equal binary 1, with those bit positions representing the combined network and subnet parts of the addresses in the subnet.

Because the network part always comes first, then the subnet part, and then the host part, the subnet mask, in binary form, cannot have interleaved 1s and 0s. Each subnet mask has one unbroken string of binary 1s on the left, with the rest of the bits as binary 0s.

After the engineer chooses the classful network and the number of subnet and host bits in a subnet, creating the binary subnet mask is easy. Just write down N 1s, S 1s, and then H 0s (assuming that N, S, and H represent the number of network, subnet, and host bits). Figure 11-17 shows the mask based on the previous example, which subnets a Class B network by creating 8 subnet bits, leaving 8 host bits.

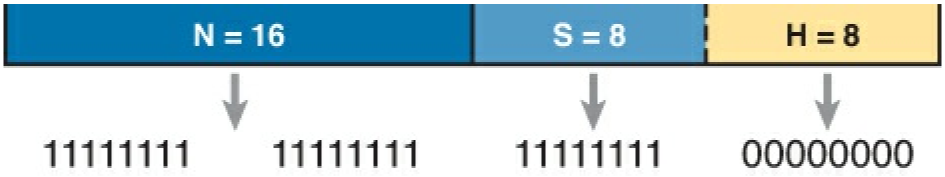


Figure 11-17. Creating the Subnet Mask—Binary—Class B Network

In addition to the binary mask shown in Figure 11-17, masks can also be written in two other formats: the familiar *dotted-decimal notation (DDN)* seen in IP addresses and an even briefer *prefix* notation. Chapter 13, "Analyzing Subnet Masks," discusses these formats and how to convert between the different formats.

Build a List of All Subnets

This final task of the subnet design step determines the actual subnets that can be used, based on all the earlier choices. The earlier design work determined the Class A, B, or C network to use, and the (one) subnet mask to use that supplies enough subnets and enough host IP addresses per subnet. But what are those subnets? How do you identify or describe a subnet? This section answers these questions.

A subnet consists of a group of consecutive numbers. Most of these numbers can be used as IP addresses by hosts. However, each subnet reserves the first and last numbers in the group, and these two numbers cannot be used as IP addresses. In particular, each subnet contains the following:

Key Topic

- **Subnet number:** Also called the *subnet ID* or *subnet address*, this number identifies the subnet. It is the numerically smallest number in the subnet. It cannot be used as an IP address by a host.
- **Subnet broadcast:** Also called the *subnet broadcast address* or *directed broadcast address*, this is the last (numerically highest) number in the subnet. It also cannot be used as an IP address by a host.

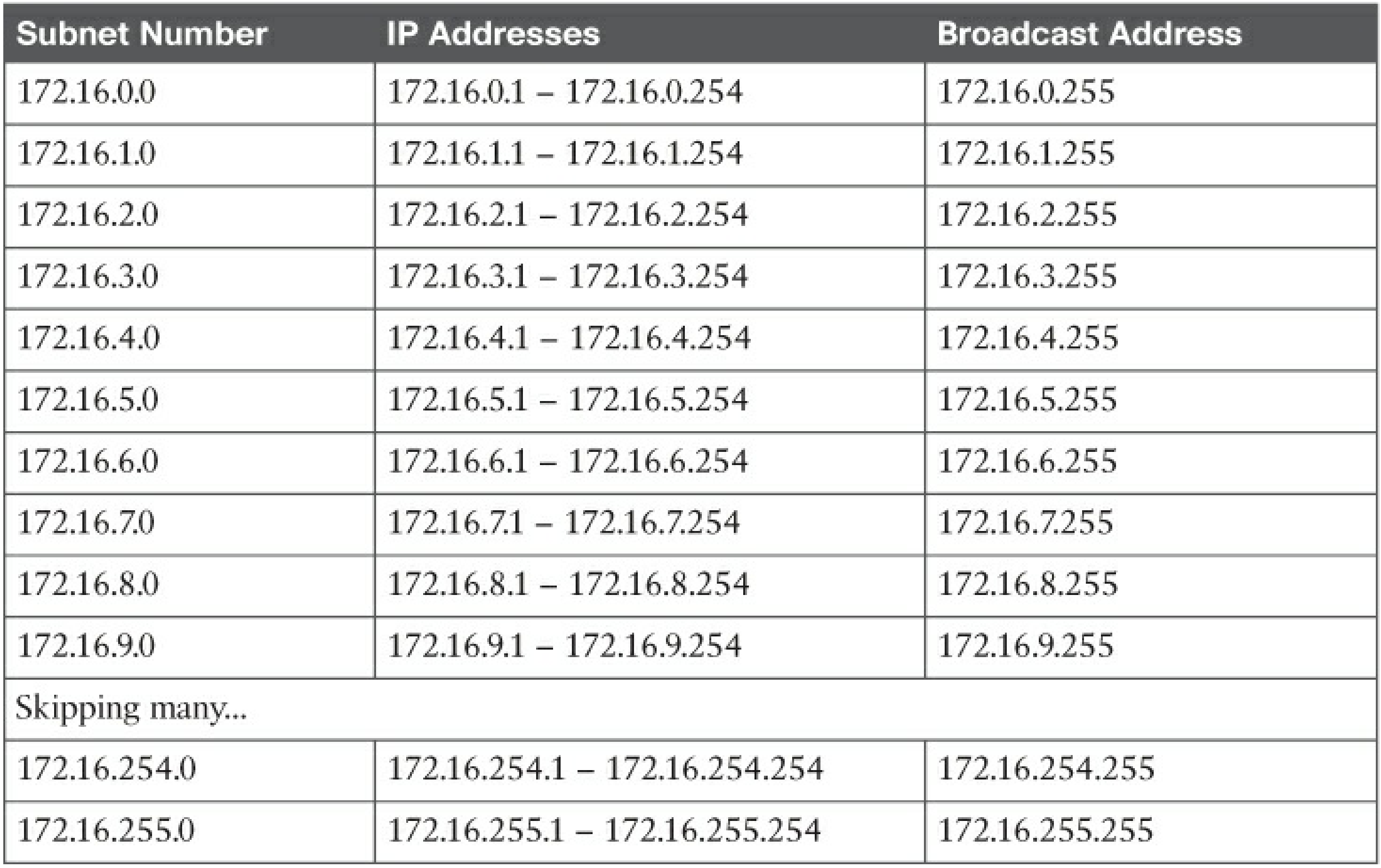
- **IP addresses:** All the numbers between the subnet ID and the subnet broadcast address can be used as a host IP address.

For example, consider the earlier case in which the design results were as follows:

Network 172.16.0.0 (Class B)
Mask 255.255.255.0 (for all subnets)

With some math, the facts about each subnet that exists in this Class B network can be calculated. In this case, Table 11-4 shows the first ten such subnets. It then skips many subnets and shows the last two (numerically largest) subnets.

Table 11-4. First Ten Subnets, Plus the Last Few, from 172.16.0.0, 255.255.255.0



Subnet Number	IP Addresses	Broadcast Address
172.16.0.0	172.16.0.1 – 172.16.0.254	172.16.0.255
172.16.1.0	172.16.1.1 – 172.16.1.254	172.16.1.255
172.16.2.0	172.16.2.1 – 172.16.2.254	172.16.2.255
172.16.3.0	172.16.3.1 – 172.16.3.254	172.16.3.255
172.16.4.0	172.16.4.1 – 172.16.4.254	172.16.4.255
172.16.5.0	172.16.5.1 – 172.16.5.254	172.16.5.255
172.16.6.0	172.16.6.1 – 172.16.6.254	172.16.6.255
172.16.7.0	172.16.7.1 – 172.16.7.254	172.16.7.255
172.16.8.0	172.16.8.1 – 172.16.8.254	172.16.8.255
172.16.9.0	172.16.9.1 – 172.16.9.254	172.16.9.255
Skipping many...		
172.16.254.0	172.16.254.1 – 172.16.254.254	172.16.254.255
172.16.255.0	172.16.255.1 – 172.16.255.254	172.16.255.255

After you have the network number and the mask, calculating the subnet IDs and other details for all subnets requires some math. In real life, most people use subnet calculators or subnet-planning tools. For the CCENT and CCNA exams, you need to be ready to find this kind of information; in this book, Chapter 19, "Subnet Design," shows you how to find all the subnets of a given network.

Plan the Implementation

The next step, planning the implementation, is the last step before actually configuring the devices to create a subnet. The engineer first needs to choose where to use each subnet. For example, at a branch office in a particular city, which subnet from the subnet planning chart (Table 11-4) should be used for each VLAN at that site? Also, for any interfaces that require static IP addresses, which addresses should be used in each case? Finally, what range of IP addresses from inside each subnet should be configured in the DHCP server, to be dynamically leased to hosts for use as their IP address? Figure 11-18 summarizes the list of implementation planning tasks.

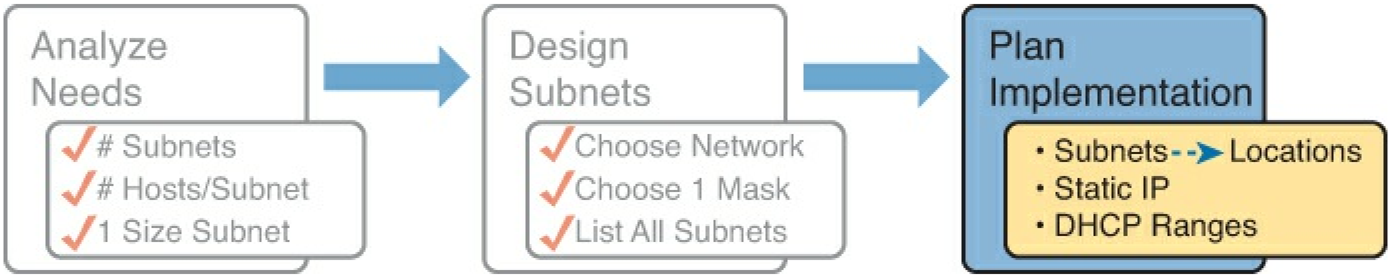
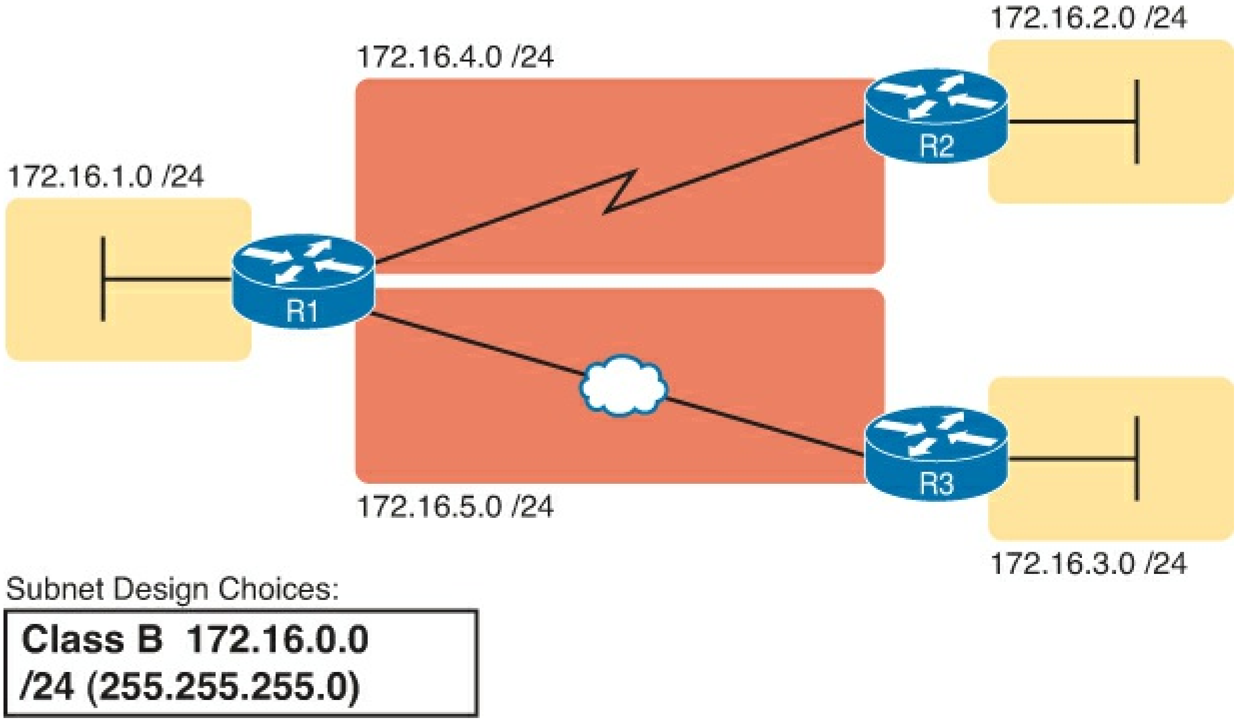


Figure 11-18. Facts Supplied to the Plan Implementation Step

Assigning Subnets to Different Locations

The job is simple: Look at your network diagram, identify each location that needs a subnet, and pick one from the table you made of all the possible subnets. Then, track it so that you know which ones you use where, using a spreadsheet or some other purpose-built subnet-planning tool. That's it! Figure 11-19 shows a sample of a completed design using Table 11-4, which happens to match the initial design sample shown way back in Figure 11-1.

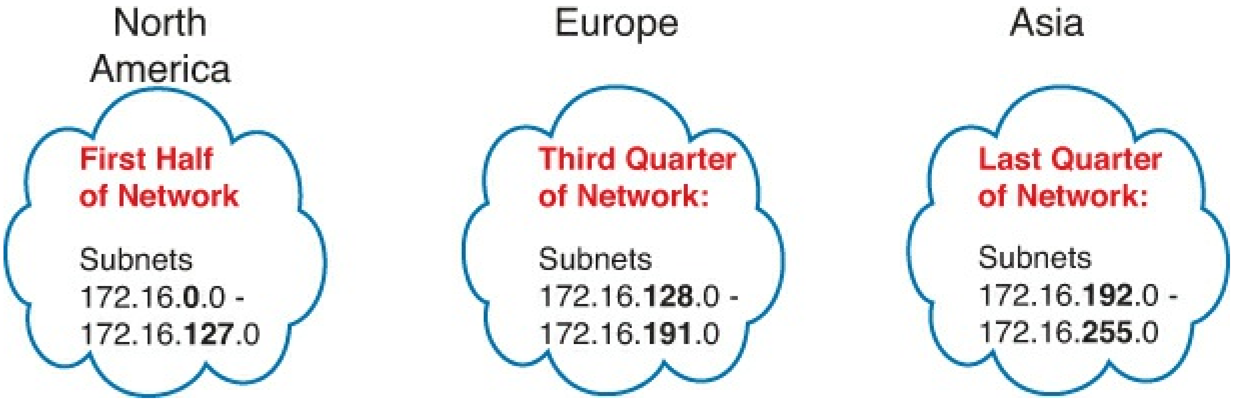


172.16.2.0 /24
172.16.4.0 /24
172.16.1.0 /24
R2
R1
R3
172.16.5.0 /24
172.16.3.0 /24
Subnet Design Choices:
Class B 172.16.0.0
/24 (255.255.255.0)

Figure 11-19. Example of Subnets Assigned to Different Locations

Although this design could have used any five subnets from Table 11-4, in real networks, engineers usually give more thought to some strategy for assigning subnets. For example, you might assign all LAN subnets lower numbers and WAN subnets higher numbers. Or you might slice off large ranges of subnets for different divisions of the company. Or you might follow that same strategy, but ignore organizational divisions in the company, paying more attention to geographies.

For example, for a U.S.-based company with a smaller presence in both Europe and Asia, you might plan to reserve ranges of subnets based on continent. This kind of choice is particularly useful when later trying to use a feature called route summarization, as discussed in Chapter 21, "Route Summarization." Figure 11-20 shows the general idea using the same subnets from Table 11-4 again.



North America
Europe
Asia
First Half of Network
Subnets 172.16.0.0 - 172.16.127.0
Third Quarter of Network:
Subnets 172.16.128.0 - 172.16.191.0
Last Quarter of Network:
Subnets 172.16.192.0 - 172.16.255.0

Figure 11-20. Reserving 50% of Subnets for the U.S. and 25% Each for Europe and Asia

Choose Static and Dynamic Ranges per Subnet

Devices receive their IP address and mask assignment in one of two ways: dynamically by using DHCP or statically through configuration. For DHCP to work, the network engineer must tell the DHCP server the subnets for which it must assign IP addresses. Additionally, that configuration limits the DHCP server to only a subset of the addresses in the subnet. For static addresses, you simply configure the device to tell it what IP address and mask to use.

To keep things as simple as possible, most shops use a strategy to separate the static IP addresses on one end of each subnet, and the DHCP-assigned dynamic addresses on the other. It does not really matter whether the static addresses sit on the low end of the range of addresses or the high end.

For example, imagine that the engineer decides that, for the LAN subnets in Figure 11-19, the DHCP pool comes from the high end of the range, namely, addresses that end in .101 through .254. (The address that ends in .255 is, of course, reserved.) The engineer also assigns static addresses from the lower end, with addresses ending in .1 through .100. Figure 11-21 shows the idea.

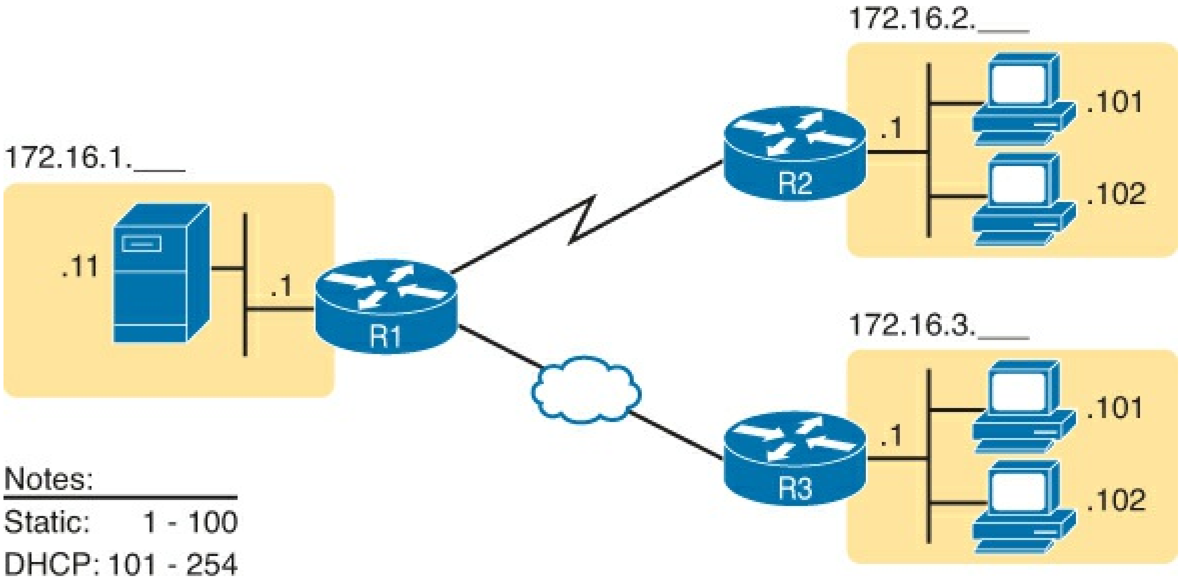


Figure 11-21. Static from the Low End and DHCP from the High End

Figure 11-21 shows all three routers with statically assigned IP addresses that end in .1. The only other static IP address in the figure is assigned to the server on the left, with address 172.16.1.11 (abbreviated simply as .11 in the figure).

On the right, each LAN has two PCs that use DHCP to dynamically lease their IP addresses. DHCP servers often begin by leasing the addresses at the bottom of the range of addresses, so in each LAN, the hosts have leased addresses that end in .101 and .102, which are at the low end of the range chosen by design.

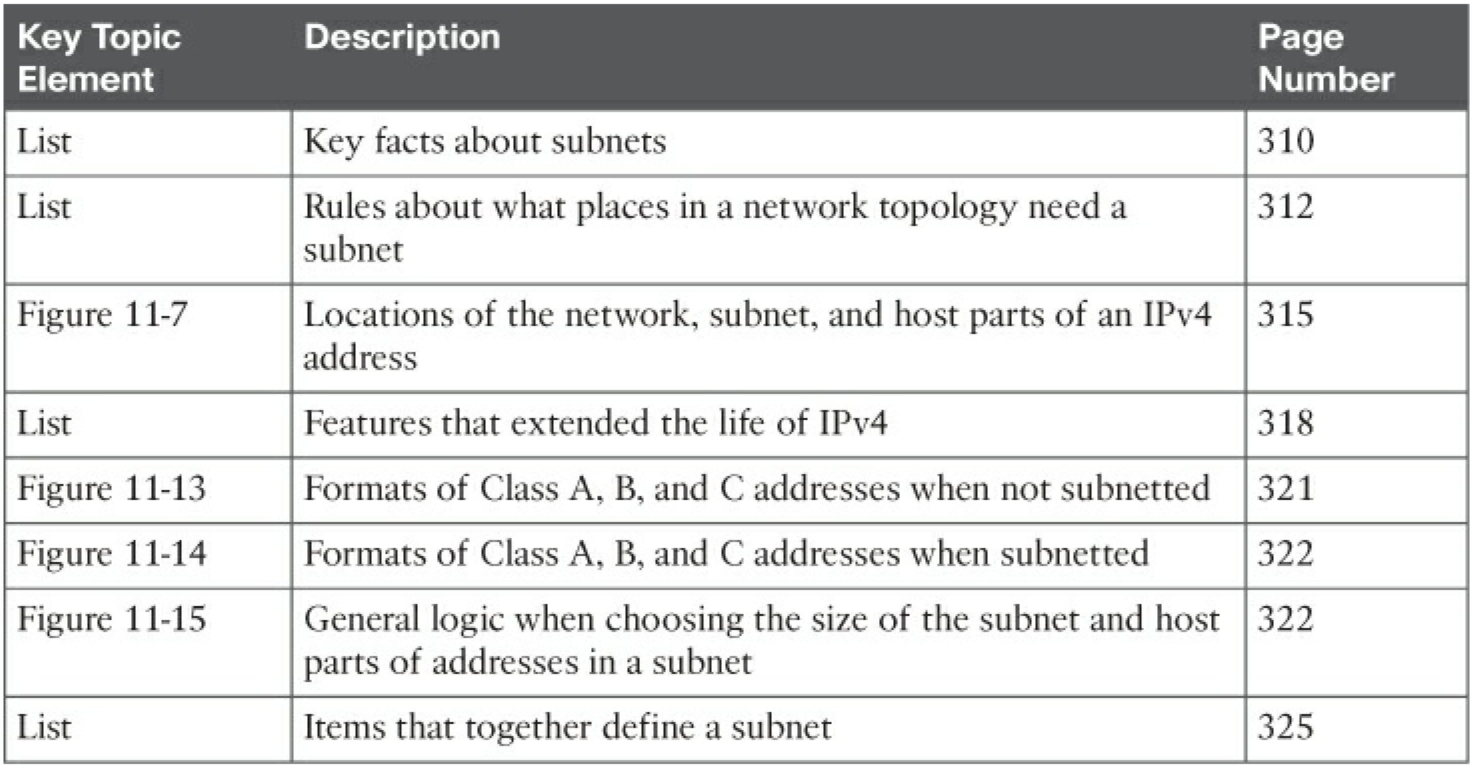
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 11-5 lists these key topics and where each is discussed.

Key Topic

Table 11-5. Key Topics for Chapter 11



Key Topic Element	Description	Page Number
List	Key facts about subnets	310
List	Rules about what places in a network topology need a subnet	312
Figure 11-7	Locations of the network, subnet, and host parts of an IPv4 address	315
List	Features that extended the life of IPv4	318
Figure 11-13	Formats of Class A, B, and C addresses when not subnetted	321
Figure 11-14	Formats of Class A, B, and C addresses when subnetted	322
Figure 11-15	General logic when choosing the size of the subnet and host parts of addresses in a subnet	322
List	Items that together define a subnet	325

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists for you to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

subnet
network
classful network
variable-length subnet masks (VLSM)
network part
subnet part
host part
public IP network
private IP network
subnet mask

Chapter 12. Analyzing Classful IPv4 Networks

This chapter covers the following exam topics:

Troubleshooting

Troubleshoot and correct common problems associated with IP addressing and host configurations.

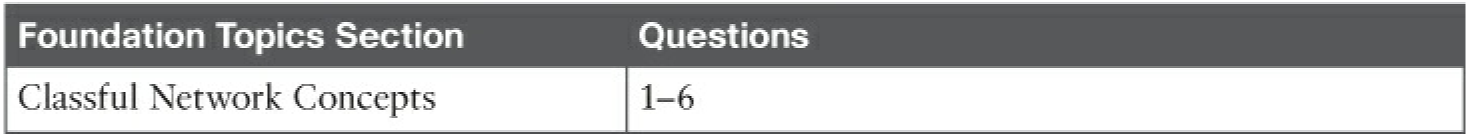
When operating a network, you often start investigating a problem based on an IP address and mask. Based on the IP address alone, you should be able to determine several facts about the Class A, B, or C network in which the IP address resides. These facts can be useful when troubleshooting some networking problems.

This chapter lists the key facts about classful IP networks and explains how to discover these facts. Following that, this chapter lists some practice problems. Before moving to the next chapter, you should practice until you can consistently determine all these facts, quickly and confidently, based on an IP address.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 12-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Classful Network Concepts	1–6

1. Which of the following are not valid Class A network IDs? (Choose two answers.)
   - **a.** 1.0.0.0
   - **b.** 130.0.0.0
   - **c.** 127.0.0.0
   - **d.** 9.0.0.0
2. Which of the following are not valid Class B network IDs?
   - **a.** 130.0.0.0
   - **b.** 191.255.0.0
   - **c.** 128.0.0.0
   - **d.** 150.255.0.0
   - **e.** All are valid Class B network IDs
3. Which of the following are true about IP address 172.16.99.45's IP network? (Select two answers.)
   - **a.** The network ID is 172.0.0.0.
   - **b.** The network is a Class B network.
   - **c.** The default mask for the network is 255.255.255.0.
   - **d.** The number of host bits in the unsubnetted network is 16.
4. Which of the following are true about IP address 192.168.6.7's IP network? (Select two answers.)
   - **a.** The network ID is 192.168.6.0.
   - **b.** The network is a Class B network.
   - **c.** The default mask for the network is 255.255.255.0.
   - **d.** The number of host bits in the unsubnetted network is 16.
5. Which of the following is a network broadcast address?
   - **a.** 10.1.255.255
   - **b.** 192.168.255.1
   - **c.** 224.1.1.255
   - **d.** 172.30.255.255
6. Which of the following is a Class A, B, or C network ID?
   - **a.** 10.1.0.0
   - **b.** 192.168.1.0
   - **c.** 127.0.0.0
   - **d.** 172.20.0.1

Answers to the "Do I Know This Already?" quiz:

1 B and C **2** E **3** B and D **4** A and C **5** D **6** B

Foundation Topics

Classful Network Concepts

Imagine that you have a job interview for your first IT job. As part of the interview, you’re given an IPv4 address and mask: 10.4.5.99, 255.255.255.0. What can you tell the interviewer about the classful network (in this case, the Class A network) in which the IP address resides?

This section, the first of two major sections in this chapter, reviews the concepts of *classful IP networks* (in other words, Class A, B, and C networks). In particular, this chapter examines how to begin with a single IP address and then determine the following facts:

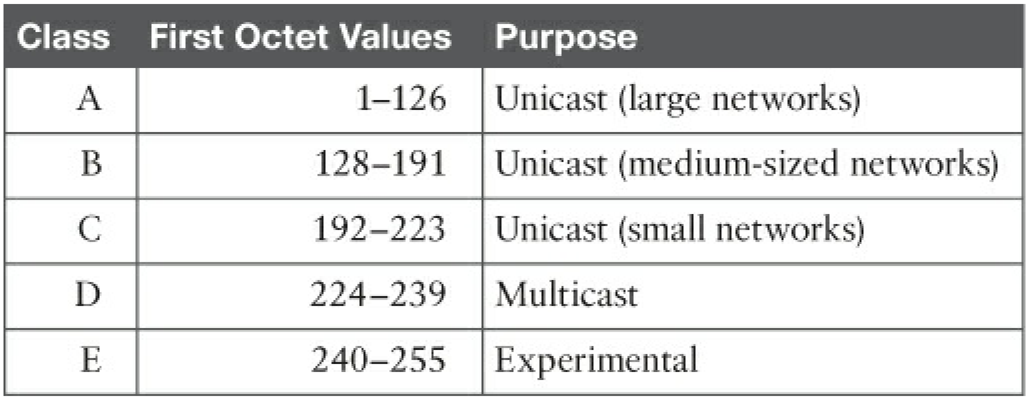
- Class (A, B, or C)
- Default mask
- Number of network octets/bits
- Number of host octets/bits
- Number of host addresses in the network
- Network ID
- Network broadcast address
- First and last usable address in the network

IPv4 Network Classes and Related Facts

IP version 4 (IPv4) defines five address classes. Three of the classes, Classes A, B, and C, consist of unicast IP addresses. Unicast addresses identify a single host or interface so that the address uniquely identifies the device. Class D addresses serve as multicast addresses, so that one packet sent to a Class D multicast IPv4 address can actually be delivered to multiple hosts. Finally, Class E addresses are experimental.

The class can be identified based on the value of the first octet of the address, as shown in Table 12-2.

Table 12-2. IPv4 Address Classes Based on First Octet Values

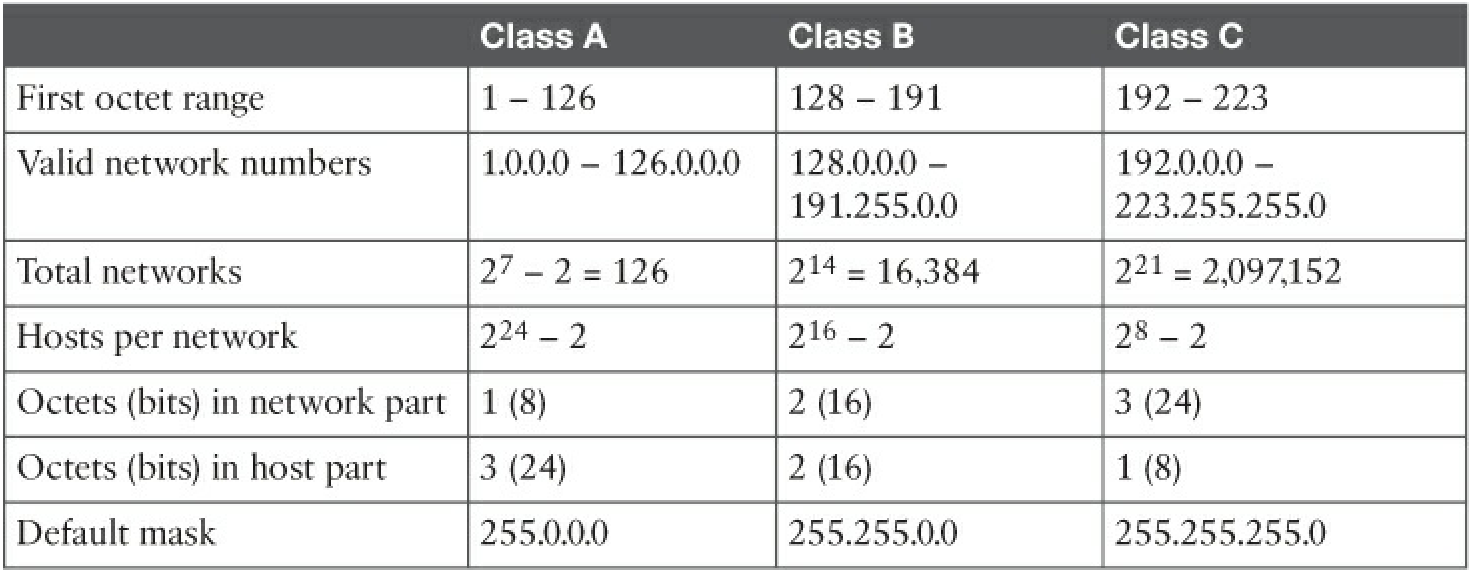


Class	First Octet Values	Purpose
A	1–126	Unicast (large networks)
B	128–191	Unicast (medium-sized networks)
C	192–223	Unicast (small networks)
D	224–239	Multicast
E	240–255	Experimental

CCENT and CCNA focus mostly on the unicast classes (A, B, and C) rather than Classes D and E. After you identify the class as either A, B, or C, many other related facts can be derived just through memorization. Table 12-3 lists that information for reference and later study; each of these concepts is described in this chapter.

Key Topic

Table 12-3. Key Facts for Classes A, B, and C



	Class A	Class B	Class C
First octet range	1 – 126	128 – 191	192 – 223
Valid network numbers	1.0.0.0 – 126.0.0.0	128.0.0.0 – 191.255.0.0	192.0.0.0 – 223.255.255.0
Total networks	$2^7 - 2 = 126$	$2^{14} = 16,384$	$2^{21} = 2,097,152$
Hosts per network	$2^{24} - 2$	$2^{16} - 2$	$2^8 - 2$
Octets (bits) in network part	1 (8)	2 (16)	3 (24)
Octets (bits) in host part	3 (24)	2 (16)	1 (8)
Default mask	255.0.0.0	255.255.0.0	255.255.255.0

Actual Class A, B, and C Networks

Table 12-3 lists the range of Class A, B, and C network numbers. However, some key points can be lost just referencing a table of information. This section examines the Class A, B, and C network numbers, focusing on the more important points and the exceptions and unusual cases.

First, the number of networks from each class significantly differs. Only 126 Class A networks exist: network 1.0.0.0, 2.0.0.0, 3.0.0.0, and so on, up through network 126.0.0.0. However, 16,384 Class B networks exist, with over 2 million Class C networks.

Next, note that the size of networks from each class also significantly differs. Each Class A network is relatively large—over 16 million host IP addresses per network—so they were originally intended to be used by the largest companies and organizations. Class B networks are smaller, with over 65,000 hosts per network. Finally, Class C networks, intended for small organizations, have 254 hosts in each network. Figure 12-1 summarizes those facts.

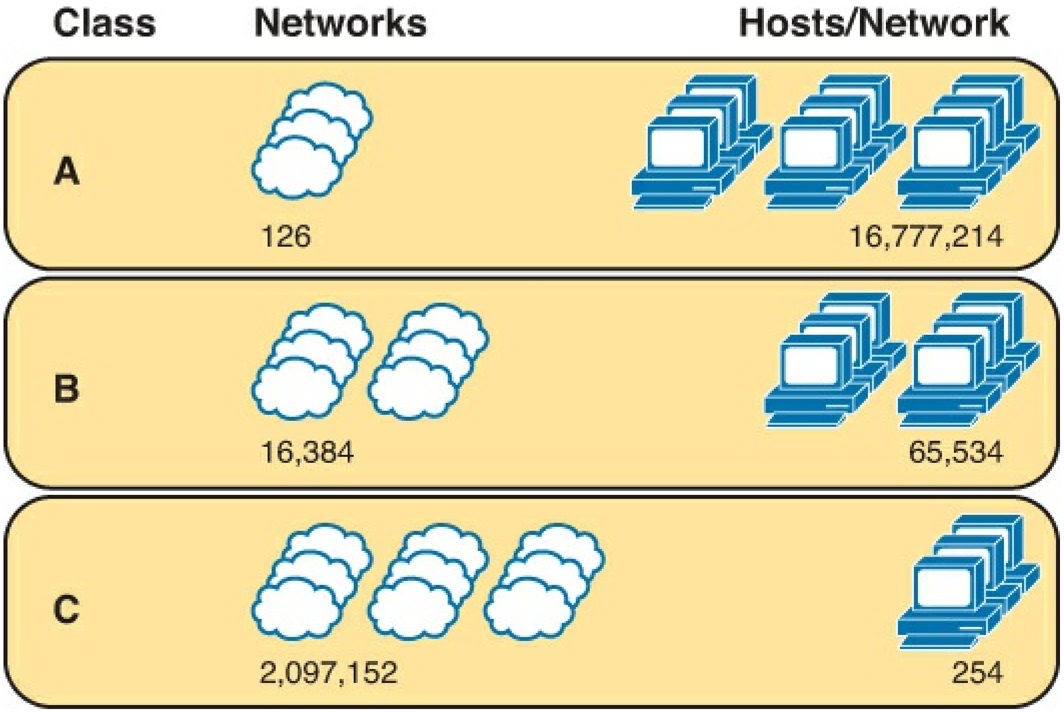


Figure 12-1. Numbers and Sizes of Class A, B, and C Networks

Address Formats

In some cases, an engineer might need to think about a Class A, B, or C network as if the network has not been subdivided through the subnetting process. In such a case, the addresses in the classful network have a structure with two parts: the *network part* (sometimes called the *prefix*) and the *host part*. Then, comparing any two IP addresses in one network, the following observations can be made:

Key Topic

The addresses in the same network have the same values in the network part.

The addresses in the same network have different values in the host part.

For example, in Class A network 10.0.0.0, by definition, the network part consists of the first octet. As a result, all addresses have an equal value in the network part, namely a 10 in the first octet. If you then compare any two addresses in the network, the addresses have a different value in the last three octets (the host octets). For example, IP addresses 10.1.1.1 and 10.1.1.2 have the same value (10) in the network part, but different values in the host part.

Figure 12-2 shows the format and sizes (in number of bits) of the network and host parts of IP addresses in Class A, B, and C networks, before any subnetting has been applied.

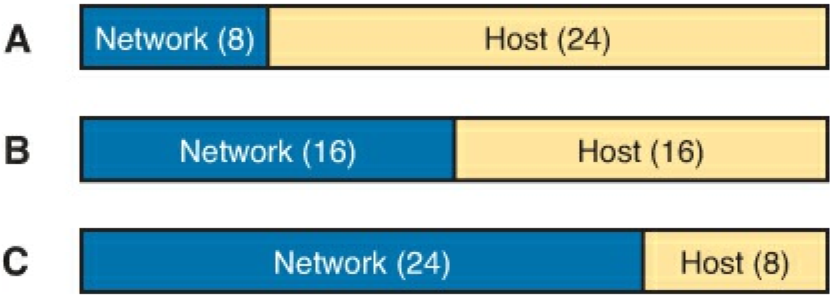


Figure 12-2. Sizes (Bits) of the Network and Host Parts of Unsubnetted Classful Networks

Default Masks

Although we humans can easily understand the concepts behind Figure 12-2, computers prefer numbers. To communicate those same ideas to computers, each network class has an associated *default mask* that defines the size of the network and host parts of an unsubnetted Class A, B, and C network. To do so, the mask lists binary 1s for the bits considered to be in the network part and binary 0s for the bits considered to be in the host part.

For example, Class A network 10.0.0.0 has a network part of the first single octet (8 bits) and a host part of last three octets (24 bits). As a result, the Class A default mask is 255.0.0.0, which in binary is

11111111 00000000 00000000 00000000

Figure 12-3 shows default masks for each network class, both in binary and dotted-decimal format.

Key Topic

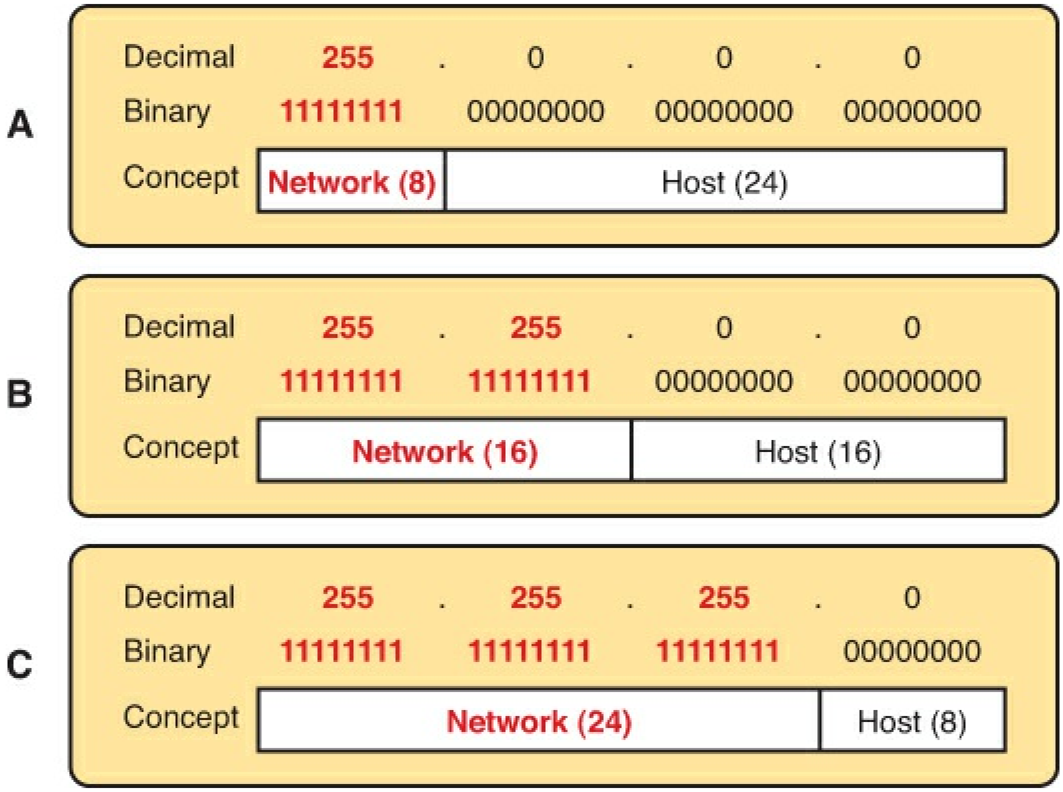

A
Decimal
255 . 0 . 0 . 0
Binary
11111111 00000000 00000000 00000000
Concept
Network (8)
Host (24)
B
Decimal
255 . 255 . 0 . 0
Binary
11111111 11111111 00000000 00000000
Concept
Network (16)
Host (16)
C
Decimal
255 . 255 . 255 . 0
Binary
11111111 11111111 11111111 00000000
Concept
Network (24)
Host (8)

Figure 12-3. Default Masks for Classes A, B, and C

Note

Decimal 255 converts to the binary value 11111111. Decimal 0, converted to 8-bit binary, is 00000000. See Appendix A, "Numeric Reference Tables," for a conversion table.

Number of Hosts per Network

Calculating the number of hosts per network requires some basic binary math. First, consider a case where you have a single binary digit. How many unique values are there? There are, of course, two values: 0 and 1. With 2 bits, you can make four combinations: 00, 01, 10, and 11. As it turns out, the total combination of unique values you can make with N bits is 2^N.

Host addresses—the IP addresses assigned to hosts—must be unique. The host bits exist for the purpose of giving each host a unique IP address by virtue of having a different value in the host part of the addresses. So, with H host bits, 2^H unique combinations exist.

However, the number of hosts in a network is not 2^H; instead, it is $2^H - 2$. Each network reserves two numbers that would have otherwise been useful as host addresses, but have instead been reserved for special use: one for the network ID and one for the network broadcast address. As a result, the formula to calculate the number of host addresses per Class A, B, or C network is

Key Topic

$$2^H - 2$$

where H is the number of host bits.

Deriving the Network ID and Related Numbers

Each classful network has four key numbers that describe the network. You can derive these four numbers if you start with just one IP address in the network. The numbers are as follows:

- Network number
- First (numerically lowest) usable address
- Last (numerically highest) usable address
- Network broadcast address

First, consider both the network number and first usable IP address. The *network number*, also called the *network ID* or *network address*, identifies the network. By definition, the network number is the numerically lowest number in the network. However, to prevent any ambiguity, the people that made up IP addressing added the restriction that the network number cannot be assigned as an IP address. So, the lowest number in the network is the network ID. Then, the first (numerically lowest) host IP address is *one larger than* the network number.

Next, consider the network broadcast address along with the last (numerically highest) usable IP address. The TCP/IP RFCs define a network broadcast address as a special address in each network. This broadcast address could be used as the destination address in a packet, and the routers would forward a copy of that one packet to all hosts in that classful network. Numerically, a network broadcast address is always the highest (last) number in the network. As a result, the highest (last) number usable as an IP address is the address that is simply *one less than* the network broadcast address.

Simply put, if you can find the network number and network broadcast address, finding the first and last usable IP addresses in the network is easy. For the exam, you should be able to find all four values with ease; the process is as follows:

Key Topic

Step 1. Determine the class (A, B, or C) based on the first octet.
Step 2. Mentally divide the network and host octets based on the class.
Step 3. To find the network number, change the IP address's host octets to 0.
Step 4. To find the first address, add 1 to the fourth octet of the network ID.
Step 5. To find the broadcast address, change the network ID's host octets to 255.
Step 6. To find the last address, subtract 1 from the fourth octet of the network broadcast address.

The written process actually looks harder than it is. Figure 12-4 shows an example of the process, using Class A IP address 10.1.2.3, with the circled numbers matching the process.

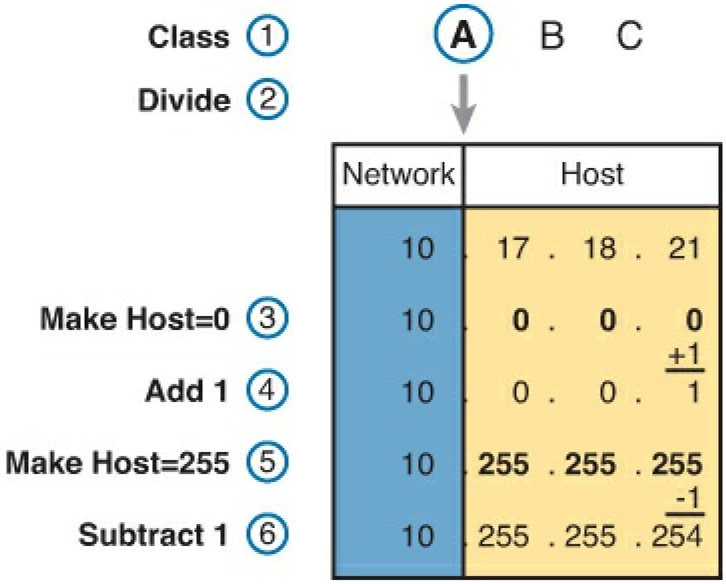


Figure 12-4. Example of Deriving the Network ID and Other Values from 10.17.18.21

Figure 12-4 shows the identification of the class as Class A (Step 1) and the number of network/host octets as 1 and 3, respectively. So, to find the network ID at Step 3, the figure copies only the first octet, setting the last three (host) octets to 0. At Step 4, just copy the network ID and add 1 to the fourth octet. Similarly, to find the broadcast address at Step 5, copy the network octets, but set the host octets to 255. Then, at Step 6, subtract 1 from the fourth octet to find the last (numerically highest) usable IP address.

Just to show an alternative example, consider IP address 172.16.8.9. Figure 12-5 shows the process applied to this IP address.

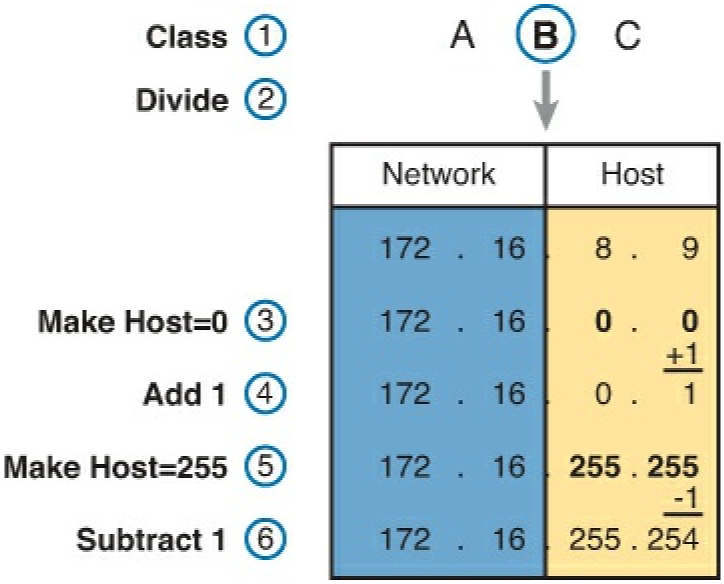


Figure 12-5. Example Deriving the Network ID and Other Values from 172.16.8.9

Figure 12-5 shows the identification of the class as Class B (Step 1) and the number of network/host octets as 2 and 2, respectively. So, to find the network ID at Step 3, the figure copies only the first two octets, setting the last two (host) octets to 0. Similarly, Step 5 shows the same action, but with the last two (host) octets being set to 255.

Unusual Network IDs and Network Broadcast Addresses

Some of the more unusual numbers in and around the range of Class A, B, and C network numbers can cause some confusion. This section lists some examples of numbers that make many people make the wrong assumptions about the meaning of the number.

For Class A, the first odd fact is that the range of values in the first octet omits the numbers 0 and 127. As it turns out, what would be Class A network 0.0.0.0 was originally reserved for some broadcasting requirements, so all addresses that begin with 0 in the first octet are reserved. What would be Class A network 127.0.0.0 is still reserved because of a special address used in software testing, called the loopback address (127.0.0.1).

For Class B (and C), some of the network numbers can look odd, particularly if you fall into a habit of thinking that 0s at the end means the number is a network ID, and 255s at the end means it's a network broadcast address. First, Class B network numbers range from 128.0.0.0 to 191.255.0.0, for a total of 2^{14} networks. However, even the very first (lowest number) Class B network number (128.0.0.0) looks a little like a Class A network number, because it ends with three 0s. However, the first octet is 128, making it a Class B network with a two-octet network part (128.0).

For another Class B example, the high end of the Class B range also might look strange at first glance (191.255.0.0), but this is indeed the numerically highest of the valid Class B network numbers. This network's broadcast address, 191.255.255.255, might look a little like a Class A broadcast address because of the three 255s at the end, but it is indeed the broadcast address of a Class B network.

Other valid Class B network IDs that look unusual include 130.0.0.0, 150.0.0.0, 155.255.0.0, and 190.0.0.0. All of these follow the convention of a value from 128 to 191 in the first octet, a value from 0 to 255 in the second octet, and two more 0s, so they are indeed valid Class B network IDs.

Class C networks follow the same general rules as Class B, but with the first three octets defining the network. The network numbers range from 192.0.0.0 to 223.255.255.0, with all addresses in a single network sharing the same value in the first three octets.

Similar to Class B networks, some of the valid Class C network numbers do look strange. For example, Class C network 192.0.0.0 looks a little like a Class A network because of the last three octets being 0, but because it is a Class C network, it consists of all addresses that begin with three octets equal to 192.0.0. Similarly, Class C network 223.255.255.0, another valid Class C network, consists of all addresses that begin 223.255.255.

Other valid Class C network IDs that look unusual include 200.0.0.0, 220.0.0.0, 205.255.255.0, and 199.255.255.0. All of these follow the convention of a value from 192 to 223 in the first octet, a value from 0 to 255 in both the second and third octets, and a 0 in the fourth octet.

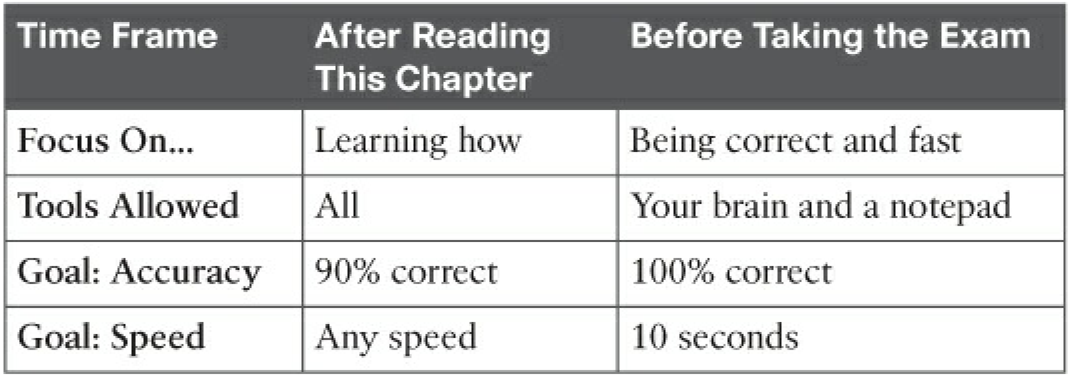
Practice with Classful Networks

As with all areas of IP addressing and subnetting, you need to practice to be ready for the CCENT and CCNA exams. Before the exam, you should master the concepts and processes in this chapter and be able to get the right answer every time—with speed. I cannot overemphasize the importance of mastering IP addressing and subnetting for the exams: Know the topics, and know them well.

However, you do not need to completely master everything in this chapter right now. You should practice some now to make sure that you understand the processes, but you can use your notes, use this book, or whatever. After you practice enough to confirm you can get the right answers using any help available, you understand the topics in this chapter well enough to move to the next chapter.

Then, before the exam, practice until you master the topics in this chapter and can move pretty fast. Table 12-4 summarizes the key concepts and suggestions for this two-phase approach.

Table 12-4. Keep-Reading and Take-Exam Goals for This Chapter's Topics

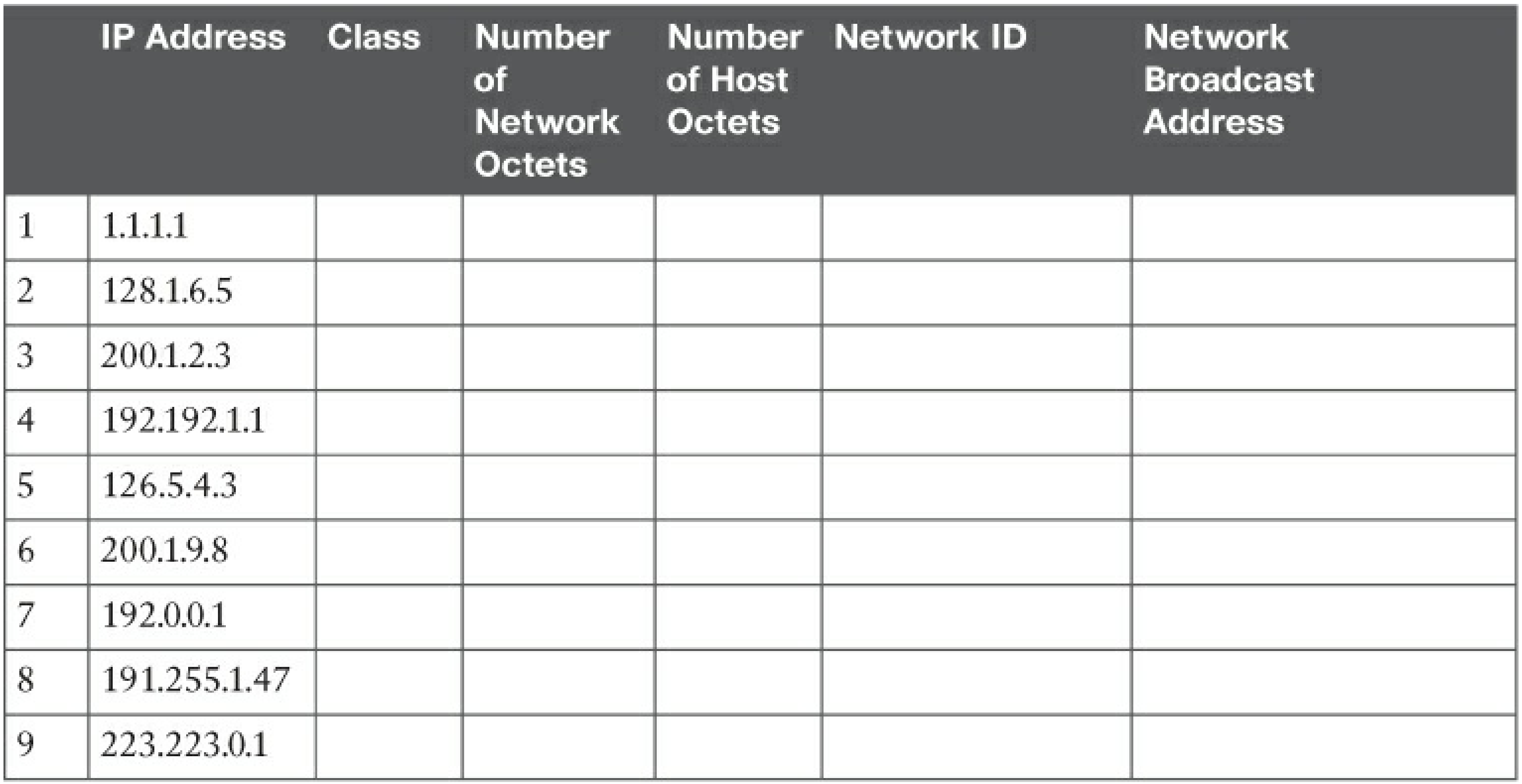


Time Frame	After Reading This Chapter	Before Taking the Exam
Focus On...	Learning how	Being correct and fast
Tools Allowed	All	Your brain and a notepad
Goal: Accuracy	90% correct	100% correct
Goal: Speed	Any speed	10 seconds

Practice Deriving Key Facts Based on an IP Address

Practice finding the various facts that can be derived from an IP address, as discussed throughout this chapter. To do so, complete Table 12-5.

Table 12-5. Practice Problems: Find the Network ID and Network Broadcast



	IP Address	Class	Number of Network Octets	Number of Host Octets	Network ID	Network Broadcast Address
1	1.1.1.1					
2	128.1.6.5					
3	200.1.2.3					
4	192.192.1.1					
5	126.5.4.3					
6	200.1.9.8					
7	192.0.0.1					
8	191.255.1.47					
9	223.223.0.1					

The answers are listed in the section "Answers to Earlier Practice Problems," later in this chapter.

Practice Remembering the Details of Address Classes

Tables 12-2 and 12-3, shown earlier in this chapter, summarized some key information about IPv4 address classes. Tables 12-6 and 12-7 show sparse versions of these same tables. To practice recalling those key facts, particularly the range of values in the first octet that identifies the address class, complete these tables. Then, refer to Tables 12-2 and 12-3 to check your answers. Repeat this process until you can recall all the information in the tables.

Table 12-6. Sparse Study Table Version of Table 12-2

Class	First Octet Values	Purpose
A		
B		
C		
D		
E		

Table 12-7. Sparse Study Table Version of Table 12-3

	Class A	Class B	Class C
First octet range			
Valid network numbers			
Total networks			
Hosts per network			
Octets (bits) in network part			
Octets (bits) in host part			
Default mask			

Additional Practice

For additional practice with classful networks, consider the following:

- DVD Appendix D, "Practice for Chapter 12: Analyzing Classful IPv4 Networks," has additional practice problems. This appendix also includes explanations about how to find the answer of each problem.
- Create your own problems. You can randomly choose any IP address and try to find the same information asked for by the practice problems in this section. Then, to check your work, use any subnet calculator. Most subnet calculators list the class and network ID.

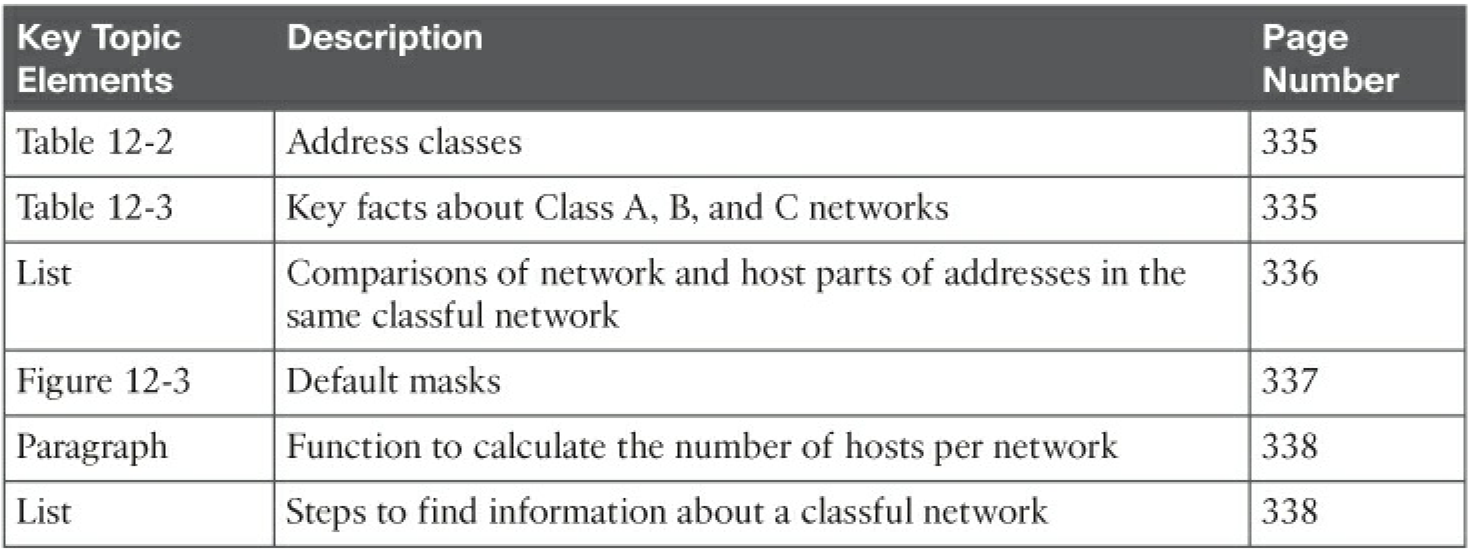
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 12-8 lists these key topics and where each is discussed.

Key Topic

Table 12-8. Key Topics for Chapter 12



Key Topic Elements	Description	Page Number
Table 12-2	Address classes	335
Table 12-3	Key facts about Class A, B, and C networks	335
List	Comparisons of network and host parts of addresses in the same classful network	336
Figure 12-3	Default masks	337
Paragraph	Function to calculate the number of hosts per network	338
List	Steps to find information about a classful network	338

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists for you to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

network
classful network
network number
network ID
network address
network broadcast address
first address
last address
network part
host part
default mask

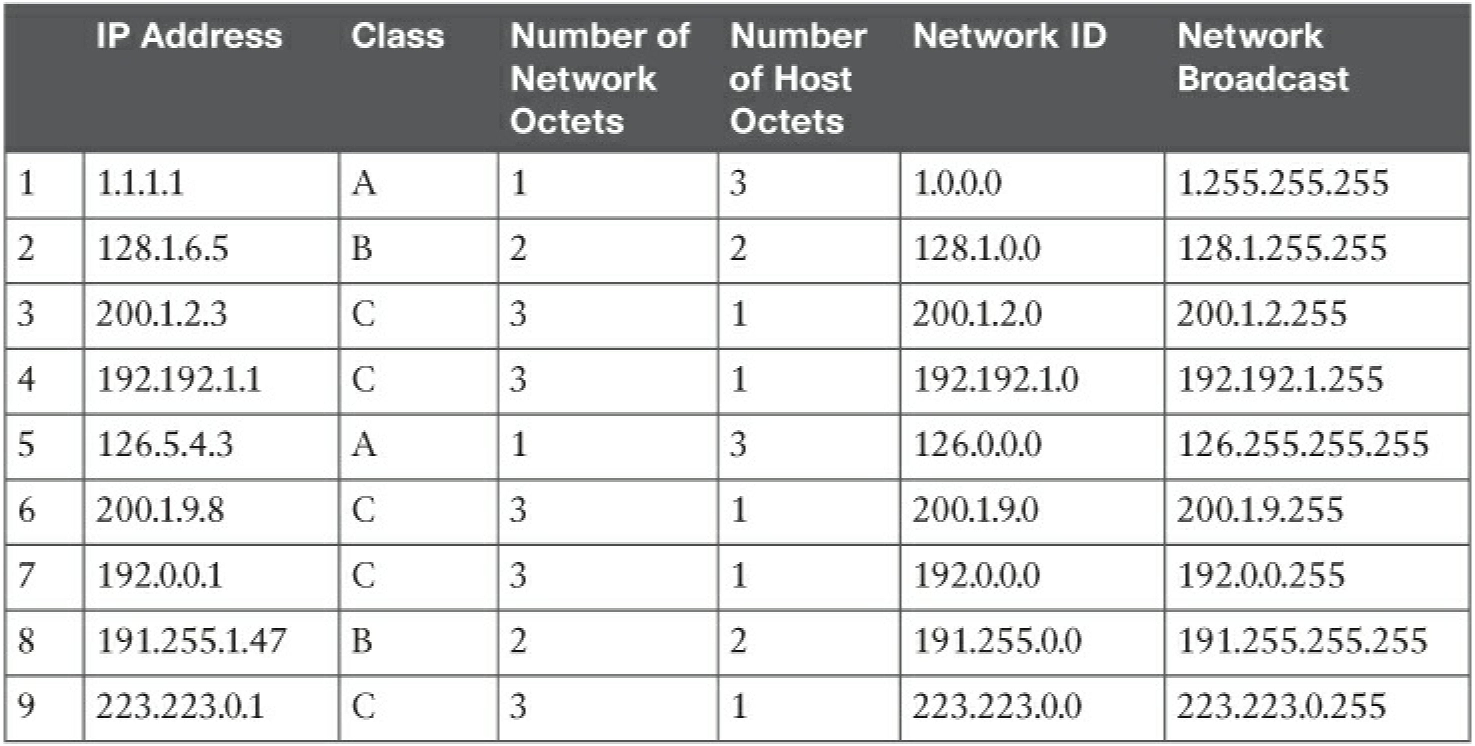
Practice

If you have not done so already, practice discovering the details of a classful network as discussed in this chapter. Refer to the earlier section "Practice with Classful Networks" for suggestions.

Answers to Earlier Practice Problems

Table 12-5, shown earlier, listed several practice problems. Table 12-9 lists the answers.

Table 12-9. Practice Problems: Find the Network ID and Network Broadcast



	IP Address	Class	Number of Network Octets	Number of Host Octets	Network ID	Network Broadcast
1	1.1.1.1	A	1	3	1.0.0.0	1.255.255.255
2	128.1.6.5	B	2	2	128.1.0.0	128.1.255.255
3	200.1.2.3	C	3	1	200.1.2.0	200.1.2.255
4	192.192.1.1	C	3	1	192.192.1.0	192.192.1.255
5	126.5.4.3	A	1	3	126.0.0.0	126.255.255.255
6	200.1.9.8	C	3	1	200.1.9.0	200.1.9.255
7	192.0.0.1	C	3	1	192.0.0.0	192.0.0.255
8	191.255.1.47	B	2	2	191.255.0.0	191.255.255.255
9	223.223.0.1	C	3	1	223.223.0.0	223.223.0.255

The class, number of network octets, and number of host octets, all require you to look at the first octet of the IP address to determine the class. If a value is between 1 and 126, inclusive, the address is a Class A address, with one network and three host octets. If a value is between 128 and 191 inclusive, the address is a Class B address, with two network and two host octets. If a value is between 192 and 223, inclusive, it is a Class C address, with three network and one host octet.

The last two columns can be found based on Table 12-3, specifically the number of network and host octets along with the IP address. To find the network ID, copy the IP address, but change the host octets to 0. Similarly, to find the network broadcast address, copy the IP address, but change the host octets to 255.

The last three problems can be confusing, and were included on purpose so that you could see an example of these unusual cases, as follows.

Answers to Practice Problem 7 (From Table 12-5)

Consider IP address 192.0.0.1. First, 192 is on the lower edge of the first octet range for Class C; as such, this address has three network and one host octet. To find the network ID, copy the address, but change the single host octet (the fourth octet) to 0, for a network ID of 192.0.0.0. It looks strange, but it is indeed the network ID.

The network broadcast address choice for problem 7 can also look strange. To find the broadcast address, copy the IP address (192.0.0.1), but change the last octet (the only host octet) to 255, for a broadcast address of 192.0.0.255. In particular, if you decide that the broadcast should be 192.255.255.255, you might have fallen into the trap of logic, like “Change all 0s in the network ID to 255s,” which is not the correct logic. Instead, change all host octets in the IP address (or network ID) to 255s.

Answers to Practice Problem 8 (From Table 12-5)

The first octet of problem 8 (191.255.1.47) sits on the upper edge of the Class B range for the first octet (128–191). As such, to find the network ID, change the last two octets (host octets) to 0, for a network ID of 191.255.0.0. This value sometimes gives people problems, because they are used to thinking that 255 somehow means the number is a broadcast address.

The broadcast address, found by changing the two host octets to 255, means that the broadcast address is 191.255.255.255. It looks more like a broadcast address for a Class A network, but it is actually the broadcast address for Class B network 191.255.0.0.

Answers to Practice Problem 9 (From Table 12-5)

The last problem with IP address 223.223.0.1 is that it’s near the high end of the Class C range. As a result, only the last (host) octet is changed to 0 to form the network ID 223.223.0.0. It looks a little like a Class B network number at first glance, because it ends in two octets of 0. However, it is indeed a Class C network ID (based on the value in the first octet).

Chapter 13. Analyzing Subnet Masks

This chapter covers the following exam topics:

Troubleshooting

Troubleshoot and correct common problems associated with IP addressing and host configurations.

The subnet mask used in one or many subnets in an IP internetwork says a lot about the intent of the subnet design. First, the mask divides addresses into two parts: *prefix* and *host*, with the host part defining the size of the subnet. Then, the class (A, B, or C) further divides the structure of addresses in a subnet, breaking the prefix part into the *network* and *subnet* parts. The subnet part defines the number of subnets that could exist inside one classful IP network, assuming that one mask is used throughout the classful network.

The subnet mask holds the key to understanding several important subnetting design points. However, to analyze a subnet mask, you first need some basic math skills with masks. The math converts masks between the three different formats used to represent a mask:

Binary

Dotted-decimal notation (DDN)

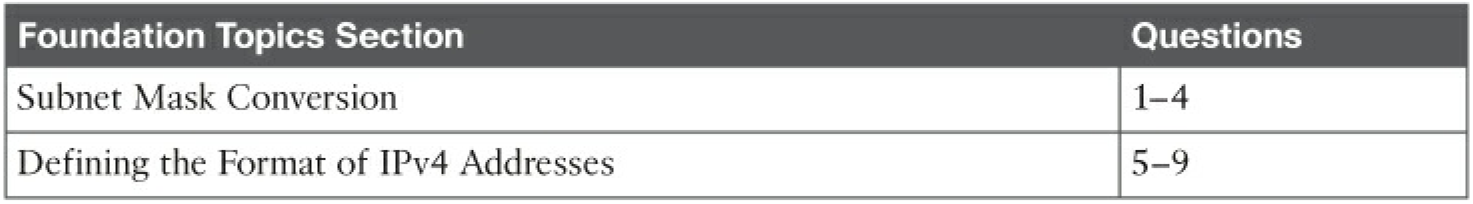
Prefix (also called CIDR)

This chapter has two major sections. The first focuses totally on the mask formats and the math used to convert between the three formats. The second section explains how to take an IP address and its subnet mask and analyze those values. In particular, it shows how to determine the three-part format of the IPv4 address and describes the facts about the subnetting design that are implied by the mask.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 13-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Subnet Mask Conversion	1–4
Defining the Format of IPv4 Addresses	5–9

1. Which of the following answers lists the prefix (CIDR) format equivalent of 255.255.254.0?
   - **a.** /19
   - **b.** /20
   - **c.** /23
   - **d.** /24
   - **e.** /25
2. Which of the following answers lists the prefix (CIDR) format equivalent of 255.255.255.240?
   - **a.** /26
   - **b.** /28
   - **c.** /27
   - **d.** /30
   - **e.** /29
3. Which of the following answers lists the dotted-decimal notation (DDN) equivalent of /24?
   - **a.** 255.255.240.0
   - **b.** 255.255.252.0
   - **c.** 255.255.255.0
   - **d.** 255.255.255.192
   - **e.** 255.255.255.240
4. Which of the following answers lists the dotted-decimal notation (DDN) equivalent of /30?
   - **a.** 255.255.255.192
   - **b.** 255.255.255.252
   - **c.** 255.255.255.240
   - **d.** 255.255.254.0

   e. 255.255.255.0

5. Working at the help desk, you receive a call and learn a user’s PC IP address and mask (10.55.66.77, mask 255.255.255.0). When thinking about this using classful logic, you determine the number of network (N), subnet (S), and host (H) bits. Which of the following is true in this case?
   - **a.** N=12
   - **b.** S=12
   - **c.** H=8
   - **d.** S=8
   - **e.** N=24
6. Working at the help desk, you receive a call and learn a user’s PC IP address and mask (192.168.9.1/27). When thinking about this using classful logic, you determine the number of network (N), subnet (S), and host (H) bits. Which of the following is true in this case?
   - **a.** N=24
   - **b.** S=24
   - **c.** H=8
   - **d.** H=7
7. An engineer is thinking about the following IP address and mask using classless IP addressing logic: 10.55.66.77, 255.255.255.0. Which of the following statements are true when using classless addressing logic? (Choose two.)
   - **a.** The network part’s size is 8 bits.
   - **b.** The prefix length is 24 bits.
   - **c.** The prefix length is 16 bits.
   - **d.** The host part’s size is 8 bits.
8. Which of the following statements is true about classless IP addressing concepts?
   - **a.** Uses a 128-bit IP address
   - **b.** Applies only for Class A and B networks
   - **c.** Separates IP addresses into network, subnet, and host parts
   - **d.** Ignores Class A, B, and C network rules
9. Which of the following masks, when used as the only mask within a Class B network, would supply enough subnet bits to support 100 subnets? (Choose two.)
   - **a.** /24
   - **b.** 255.255.255.252
   - **c.** /20
   - **d.** 255.255.252.0

Answers to the “Do I Know This Already?” quiz:

1 C **2** B **3** C **4** B **5** C **6** A **7** B and D **8** D **9** A and B

Foundation Topics

Subnet Mask Conversion

This section describes how to convert between different formats for the subnet mask. You can then use these processes when you practice. If you already know how to convert from one format to the other, go ahead and move to the section “Practice Converting Subnet Masks,” later in this chapter.

Three Mask Formats

Subnet masks can be written as 32-bit binary numbers, but not just any binary number. In particular, the binary subnet mask must follow these rules:

- The value must not interleave 1s and 0s.
- If 1s exist, they are on the left.
- If 0s exist, they are on the right.

For example, the following values would be illegal. The first is illegal because the value interleaves 0s and 1s, and the second is illegal because it lists 0s on the left and 1s on the right:

10101010 01010101 11110000 00001111

00000000 00000000 00000000 11111111

The following two binary values meet the requirements, in that they have all 1s on the left, followed by all 0s, with no interleaving of 1s and 0s:

11111111 00000000 00000000 00000000

11111111 11111111 11111111 00000000

Two alternate subnet mask formats exist so that we humans do not have to work with 32-bit binary numbers. One format, dotted-decimal notation (DDN), converts each set of 8 bits into the decimal equivalent. For example, the two previous binary masks would convert to the following DDN subnet masks, because binary 11111111 converts to decimal 255, and binary 00000000 converts to decimal 0:

255.0.0.0

255.255.255.0

Although the DDN format has been around since the beginning of IPv4 addressing, the third mask format was added later, in the early 1990s: the *prefix* format. This format takes advantage of the rule that the subnet mask starts with some number of 1s, and then the rest of the digits are 0s. Prefix format lists a slash (/) followed by the number of binary 1s in the binary mask. Using the same two examples as earlier in this section, the prefix format equivalent masks are as follows:

/8

/24

Note that although the terms *prefix* or prefix mask can be used, the terms CIDR mask or *slash mask* can also be used. This newer prefix style mask was created around the same time as the *classless interdomain routing (CIDR)* specification back in the early 1990s, and the acronym CIDR grew to be used for anything related to CIDR, including prefix-style masks. Additionally, the term *slash mask* is sometimes used because the value includes a slash mark (/).

Both in real life and on the Cisco CCENT and CCNA exams, you need to be able to think about masks in different formats. The rest of this section examines how to convert between the three formats.

Converting Between Binary and Prefix Masks

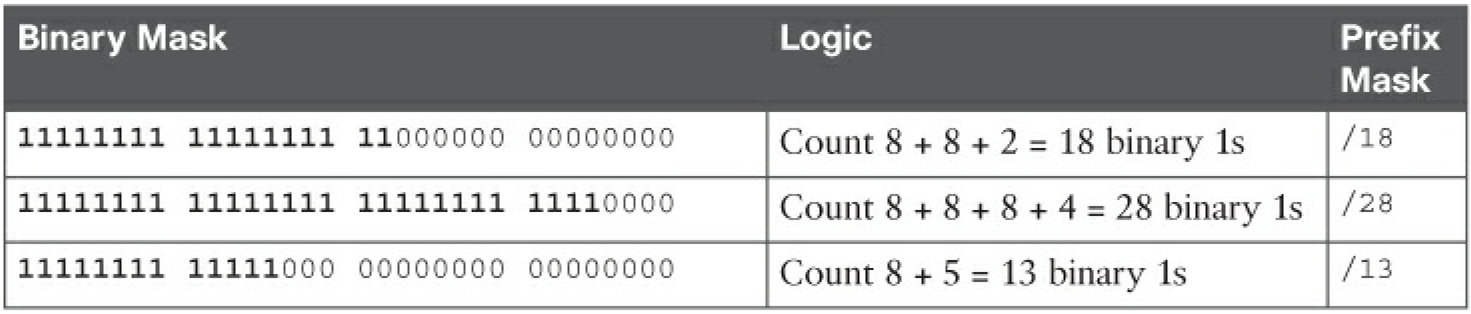
Converting between binary and prefix masks should be relatively intuitive after you know that the prefix value is simply the number of binary 1s in the binary mask. For the sake of completeness, the processes to convert in each direction are

Binary to prefix: Count the number of binary 1s in the binary mask, and write the total, in decimal, after a /.

Prefix to binary: Write P binary 1s, where P is the prefix value, followed by as many binary 0s as required to create a 32-bit number.

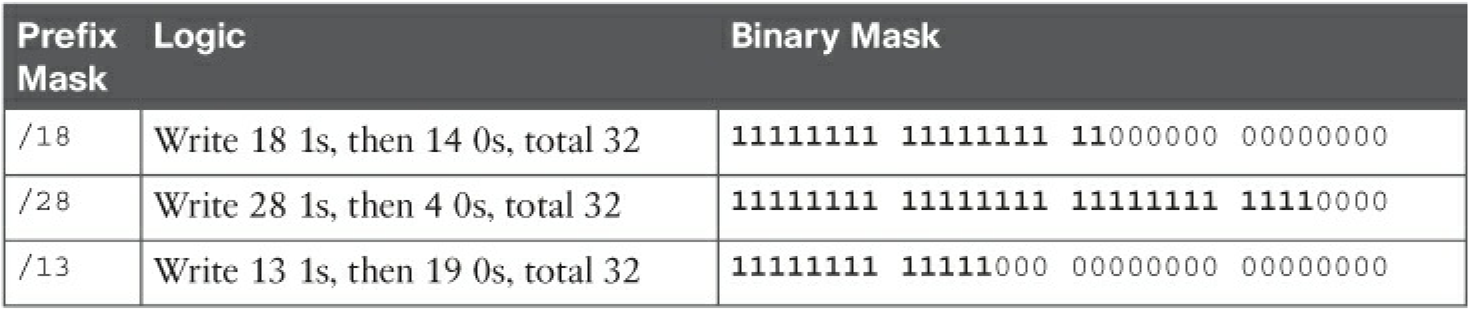
Tables 13-2 and 13-3 show some examples.

Table 13-2. Example Conversions: Binary to Prefix



Binary Mask	Logic	Prefix Mask
11111111 11111111 11000000 00000000	Count 8 + 8 + 2 = 18 binary 1s	/18
11111111 11111111 11111111 11110000	Count 8 + 8 + 8 + 4 = 28 binary 1s	/28
11111111 11111000 00000000 00000000	Count 8 + 5 = 13 binary 1s	/13

Table 13-3. Example Conversions: Prefix to Binary



Prefix Mask	Logic	Binary Mask
/18	Write 18 1s, then 14 0s, total 32	11111111 11111111 11000000 00000000
/28	Write 28 1s, then 4 0s, total 32	11111111 11111111 11111111 11110000
/13	Write 13 1s, then 19 0s, total 32	11111111 11111000 00000000 00000000

Converting Between Binary and DDN Masks

By definition, a *dotted-decimal number (DDN)* used with IPv4 addressing contains four decimal numbers, separated by dots. Each decimal number represents 8 bits. So, a single DDN shows four decimal numbers that together represent some 32-bit binary number.

Conversion from a DDN mask to the binary equivalent is relatively simple to describe, but can be laborious to perform. First, to do the conversion, the process is as follows:

> For each octet, perform a decimal-to-binary conversion.

However, depending on your comfort level with doing decimal-to-binary conversions, that process can be difficult or time-consuming. If you want to think about masks in binary for the exam, consider picking one of the following methods to do the conversion and practicing until you can do it quickly and accurately:

- Do the decimal-binary conversions, but practice your decimal-binary conversions to get fast. If you choose this path, consider the Cisco Binary Game, which you can find by searching its name at the Cisco Learning Network (CLN) (http://learningnetwork.cisco.com).
- Use the decimal-binary conversion chart in Appendix A, "Numeric Reference Tables." This lets you find the answer more quickly now, but you cannot use the chart on exam day.
- Memorize the nine possible decimal values that can be in a decimal mask, and practice using a reference table with those values.

The third method, which is the method recommended in this book, takes advantage of the fact that any and every DDN mask octet must be one of only nine values. Why? Well, remember how a binary mask cannot interleave 1s and 0s, and the 0s must be on the right? It turns out that only nine different 8-bit binary numbers conform to these rules. Table 13-4 lists the values, along with other relevant information.

Key Topic

Table 13-4. Nine Possible Values in One Octet of a Subnet Mask

Binary Mask Octet	Decimal Equivalent	Number of Binary 1s
00000000	0	0
10000000	128	1
11000000	192	2
11100000	224	3
11110000	240	4
11111000	248	5
11111100	252	6
11111110	254	7
11111111	255	8

Many subnetting processes can be done with or without binary math. Some of those processes—mask conversion included—use the information in Table 13-4. You should plan to memorize the information in the table. I recommend making a copy of the table to keep handy while you practice. (You will likely memorize the contents of this table simply by practicing the conversion process enough to get both good and fast at the conversion.)

Using the table, the conversion processes in each direction with binary and decimal masks are as follows:

Key Topic

Binary to decimal: Organize the bits into four sets of eight. For each octet, find the binary value in the table and write down the corresponding decimal value.

Decimal to binary: For each octet, find the decimal value in the table and write down the corresponding 8-bit binary value.

Tables 13-5 and 13-6 show some examples.

Table 13-5. Example Conversions: Binary to Decimal

Binary Mask	Logic	Decimal Mask
11111111 11111111 11000000 00000000	11111111 maps to 255 11000000 maps to 192 00000000 maps to 0	255.255.192.0
11111111 11111111 11111111 11110000	11111111 maps to 255 11110000 maps to 240	255.255.255.240
11111111 11111000 00000000 00000000	11111111 maps to 255 11111000 maps to 248 00000000 maps to 0	255.248.0.0

Table 13-6. Example Conversions: Decimal to Binary

Decimal Mask	Logic	Binary Mask
255.255.192.0	255 maps to 11111111 192 maps to 11000000 0 maps to 00000000	11111111 11111111 11000000 00000000
255.255.255.240	255 maps to 11111111 240 maps to 11110000	11111111 11111111 11111111 11110000
255.248.0.0	255 maps to 11111111 248 maps to 11111000 0 maps to 00000000	11111111 11111000 00000000 00000000

Converting Between Prefix and DDN Masks

When learning, the best way to convert between the prefix and decimal formats is to first convert to binary. For example, to move from decimal to prefix, first convert decimal to binary and then from binary to prefix.

For the exams, set a goal to master these conversions doing the math in your head. While learning, you will likely want to use paper. To train yourself to do all this without writing it down, instead of writing each octet of binary, just write the number of binary 1s in that octet.

Figure 13-1 shows an example with a prefix-to-decimal conversion. The left side shows the conversion to binary as an interim step. For comparison, the right side shows the binary interim step in shorthand that just lists the number of binary 1s in each octet of the binary mask.

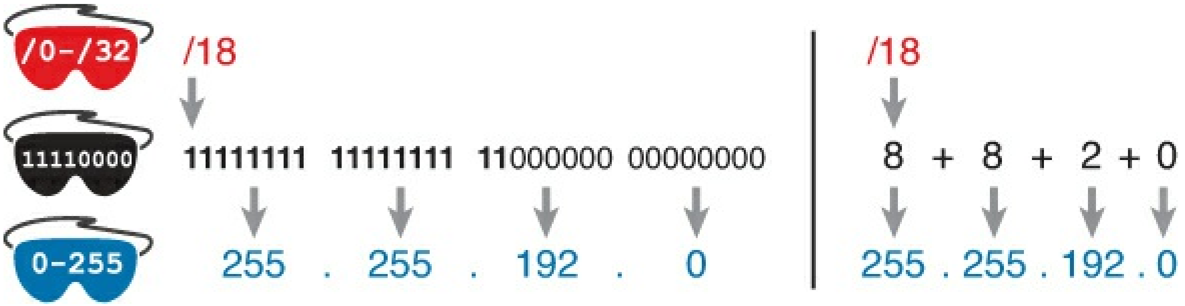


Figure 13-1. Conversion from Prefix to Decimal: Full Binary Versus Shorthand

Similarly, when converting from decimal to prefix, mentally convert to binary along the way, and as you improve, just think of the binary as the number of 1s in each octet. Figure 13-2 shows an example of such a conversion.

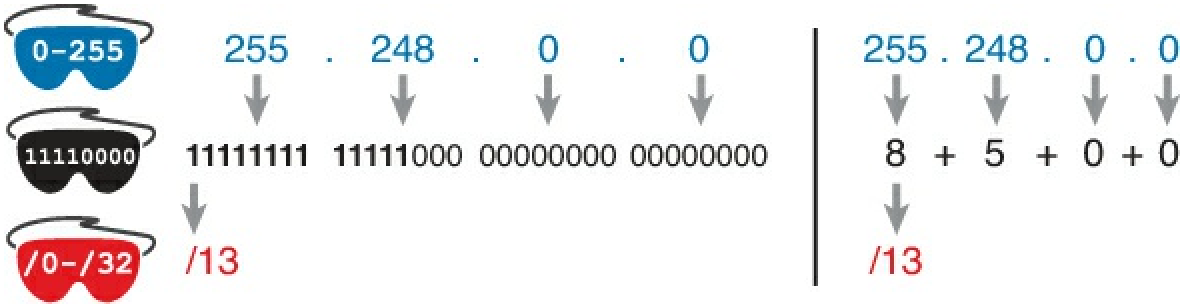


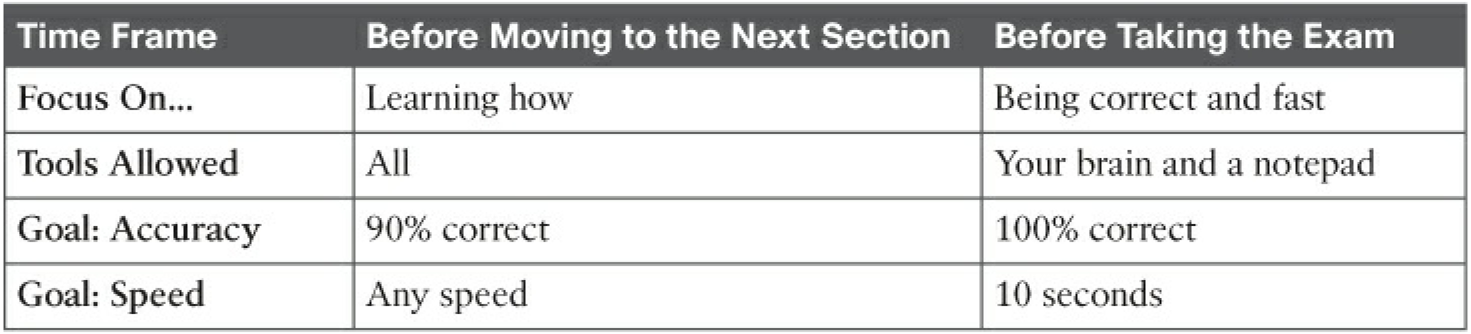
Figure 13-2. Conversion from Decimal to Prefix: Full Binary Versus Shorthand

Note that Appendix A has a table that lists all 33 legal subnet masks, with all three formats shown.

Practice Converting Subnet Masks

Before moving to the second half of this chapter, and thinking about what these subnet masks mean, first do some practice. Practice the processes discussed in this chapter until you get the right answer most of the time. Use any tools you want, and take all the time you need, until you meet the goal in Table 13-7 for being ready to move on to the next section. Later, before taking the exam, practice more until you master the topics in this chapter and can move pretty fast, as outlined in the right column of Table 13-7.

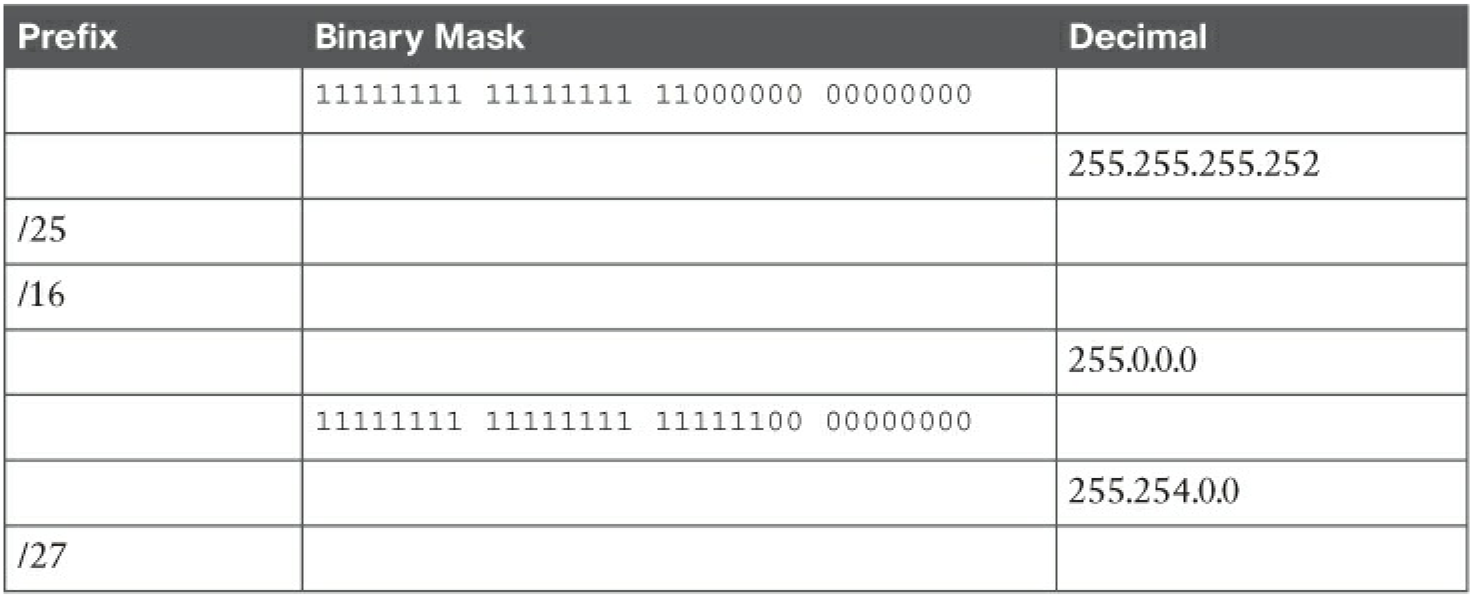
Table 13-7. Keep-Reading and Take-Exam Goals for This Chapter's Topics



Time Frame	Before Moving to the Next Section	Before Taking the Exam
Focus On...	Learning how	Being correct and fast
Tools Allowed	All	Your brain and a notepad
Goal: Accuracy	90% correct	100% correct
Goal: Speed	Any speed	10 seconds

Table 13-8 lists eight practice problems. The table has three columns, one for each mask format. Each row lists one mask, in one format. Your job is to find the mask's value in the other two formats for each row. Table 13-11, located in the section "Answers to Earlier Practice Problems," later in this chapter, lists the answers.

Table 13-8. Practice Problems: Find the Mask Values in the Other Two Formats



Prefix	Binary Mask	Decimal
	11111111 11111111 11000000 00000000	
		255.255.255.252
/25		
/16		
		255.0.0.0
	11111111 11111111 11111100 00000000	
		255.254.0.0
/27		

For additional practice converting subnet masks, consider the following:

- DVD Appendix E, "Practice for Chapter 13: Analyzing Subnet Masks," has some additional practice problems listed. This section also includes explanations as to how to find the answer of each problem.
- Create your own problems. Only 33 legal subnet masks exist, so pick one, and convert that mask to the other two formats. Then check your work based on Appendix A, which lists all mask values in all three formats. (Recommendation: Think of a prefix and convert it to binary and then decimal. Then, think of a DDN mask and convert it to binary and to prefix format.)

Note that many other subnetting problems will require you to do these conversions, so you will get extra practice as well.

Identifying Subnet Design Choices Using Masks

Subnet masks have many purposes. In fact, if ten experienced network engineers were independently asked, "What is the purpose of a subnet mask?" the engineers would likely give a variety of true answers. The subnet mask plays several roles.

This chapter focuses on one particular use of a subnet mask: defining the prefix part of the IP addresses in a subnet. The prefix part must be the same value for all addresses in a subnet. In fact, a single subnet can be defined as all IPv4 addresses that have the same value in the prefix part of their IPv4 addresses.

While the previous paragraph might sound a bit formal, the idea is relatively basic, as shown in Figure 13-3. The figure shows a network diagram, focusing on two subnets: a subnet of all addresses that begin with 172.16.2 and another subnet made of all addresses that begin with 172.16.3. In this example, the prefix—the part that has the same value in all the addresses in the subnet—is the first three octets.

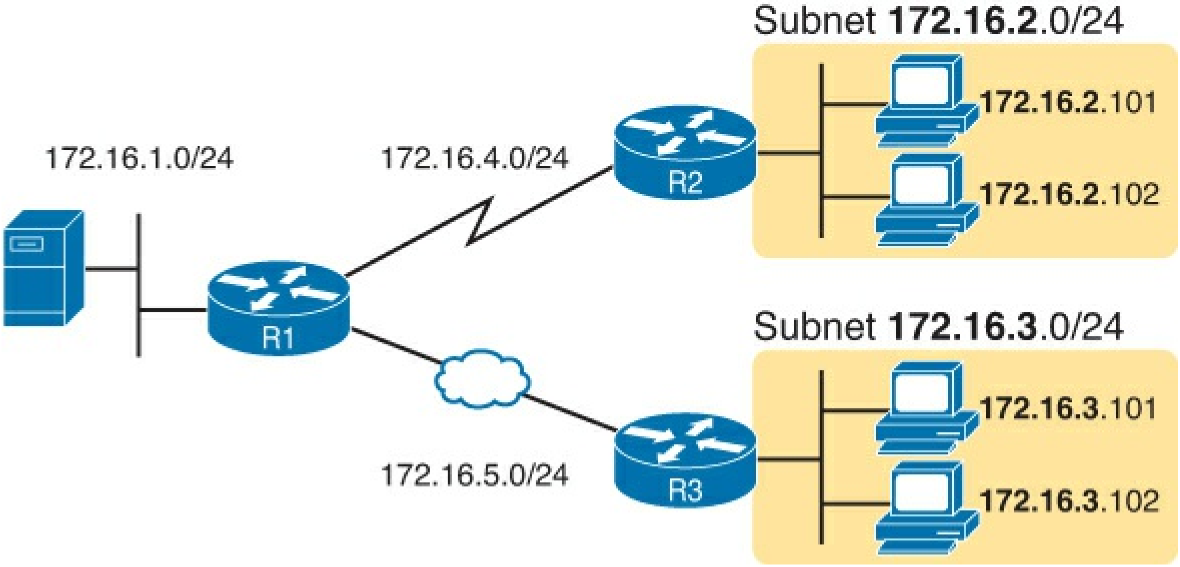


Figure 13-3. Simple Subnet Design, with Mask /24

While people can sit around a conference table and talk about how a prefix is three octets long, computers communicate that same concept using a subnet mask. In this case, the subnets use a subnet mask of /24, which means that the prefix part of the addresses is 24 bits (3 octets) long.

This section explains more about how to use a subnet mask to understand this concept of a prefix part of an IPv4 address, along with these other uses for a subnet mask. Note that this section discusses the first five items in the list.

Key Topic

- Defines the size of the prefix (combined network and subnet) part of the addresses in a subnet
- Defines the size of the host part of the addresses in the subnet
- Can be used to calculate the number of hosts in the subnet
- Provides a means for the network designer to communicate the design details—the number of subnet and host bits—to the devices in the network
- Under certain assumptions, can be used to calculate the number of subnets in the entire classful network
- Can be used in binary calculations of both the subnet ID and the subnet broadcast address

Masks Divide the Subnet's Addresses into Two Parts

The subnet mask subdivides the IP addresses in a subnet into two parts: the *prefix*, or *subnet part*, and the *host part*.

The prefix part identifies the addresses that reside in the same subnet, because all IP addresses in the same subnet have the same value in the prefix part of their addresses. The idea is much like the postal code (ZIP codes in the United States) in mailing addresses. All mailing addresses in the same town have the same postal code. Likewise, all IP addresses in the same subnet have identical values in the prefix part of their addresses.

The host part of an address identifies the host uniquely inside the subnet. If you compare any two IP addresses in the same subnet, their host parts will differ, even though the prefix parts of their addresses have the same value. To summarize these key comparisons:

Key Topic

Prefix (subnet) part: Equal in all addresses in the same subnet.

Host part: Different in all addresses in the same subnet.

For example, imagine a subnet that, in concept, includes all addresses whose first three octets are 10.1.1. So, the following list shows several addresses in this subnet:

10.1.1.**1**
10.1.1.**2**
10.1.1.**3**

In this list, the prefix or subnet part (the first three octets of 10.1.1) are equal. The host part (the last octet [in bold]) are different. So, the prefix or subnet part of the address identifies the group, and the host part identifies the specific member of the group.

The subnet mask defines the dividing line between the prefix and the host part. To do so, the mask creates a conceptual line between the binary 1s in the binary mask and the binary 0s in the mask. In short, if a mask has P binary 1s, the prefix part is P bits long and the rest of the bits are host bits. Figure 13-4 shows the general concept.

Key Topic

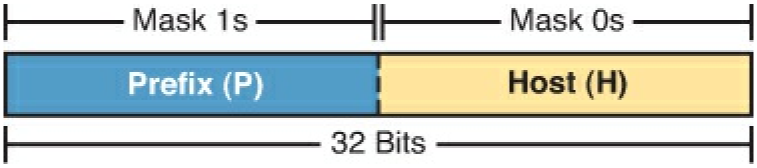

Mask 1s
Mask 0s
Prefix (P)
Host (H)
32 Bits

Figure 13-4. Prefix (Subnet) and Host Parts Defined by Masks 1s and 0s

The next figure, Figure 13-5, shows a specific example using mask 255.255.255.0. Mask 255.255.255.0 (/24) has 24 binary 1s, for a prefix length of 24 bits.

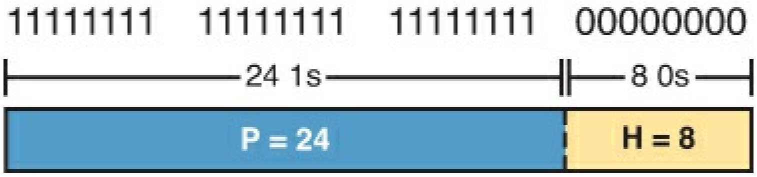

11111111 11111111 11111111 00000000
24 1s
8 0s
P = 24
H = 8

Figure 13-5. Mask 255.255.255.0: P=24, H=8

Masks and Class Divide Addresses into Three Parts

In addition to the two-part view of IPv4 addresses, you can also think about IPv4 addresses as having three parts. To do so, just apply Class A, B, and C rules to the address format to define the network part at the beginning of the address. This added logic divides the prefix into two parts: the *network* part and the *subnet* part. The class defines the length of the network part, with the subnet part simply being the rest of the prefix. Figure 13-6 shows the idea.

Key Topic

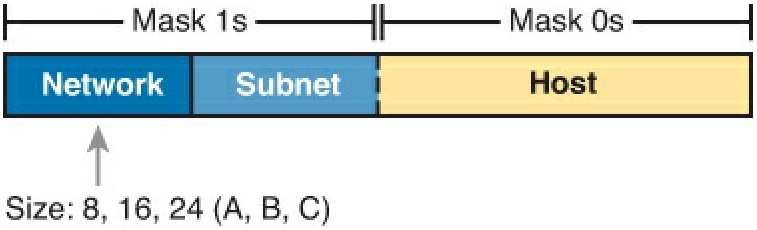

Mask 1s
Mask 0s
Network
Subnet
Host
Size: 8, 16, 24 (A, B, C)

Figure 13-6. Class Concepts Applied to Create Three Parts

The combined network and subnet parts act like the prefix because all addresses in the same subnet must have identical values in the network and subnet parts. The size of the host part remains unchanged, whether viewing the addresses as having two parts or three parts.

To be complete, Figure 13-7 shows the same example as in the previous section, with the subnet of "all addresses that begin with 10.1.1." In that example, the subnet uses mask 255.255.255.0, and the addresses are all in Class A network 10.0.0.0. The class defines 8 network bits, and the mask defines 24 prefix bits, meaning that 24 – 8 = 16 subnet bits exist. The host part remains as 8 bits per the mask.

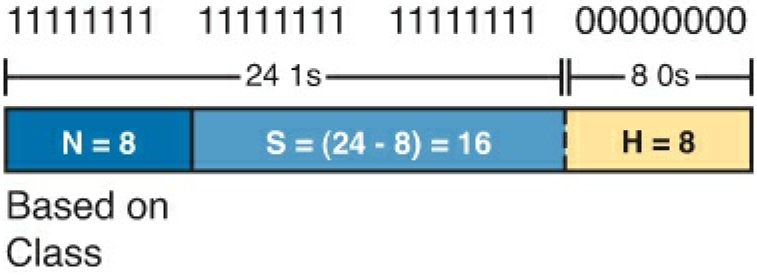

11111111 11111111 11111111 00000000
24 1s
8 0s
N = 8
S = (24 - 8) = 16
H = 8
Based on Class

Figure 13-7. Subnet 10.1.1.0, Mask 255.255.255.0: N=8, S=16, H=8

Classless and Classful Addressing

The terms *classless addressing* and *classful addressing* refer to the two different ways to think about IPv4 addresses as described so far in this chapter. Classful addressing means that you think about Class A, B, and C rules, so the prefix is separated into the network and subnet parts, as shown in Figures 13-6 and 13-7. Classless addressing means that you ignore the Class A, B, and C rules and treat the prefix part as one part, as shown in Figures 13-4 and 13-5. The following more formal definitions are listed for reference and study:

Classless addressing: The concept that an IPv4 address has two parts—the prefix part plus the host part—as defined by the mask, with *no consideration of the class* (A, B, or C).

Classful addressing: The concept that an IPv4 address has three parts—network, subnet, and host—as defined by the mask *and Class A, B, and C rules*.

> **Note**
>
> The scope of the CCENT and CCNA certifications includes two other related topics that are (unfortunately) also referenced as *classless* and *classful*. In addition to the classless and classful addressing described here, each routing protocol can be categorized as either a *classless routing protocol* or a *classful routing protocol*. Additionally, the terms *classless routing* and *classful routing* refer to some details of how Cisco routers forward (route) packets using the default route in some cases (which do not happen to be within the scope of this book). As a result, these terms can be easily confused and misused. So, when you see the words *classless* and *classful*, be careful to note the context: addressing, routing, or routing protocols.

Calculations Based on the IPv4 Address Format

After you know how to break an address down using both classless and classful addressing rules, you can easily calculate a couple of important facts using some basic math formulas.

First, for any subnet, after you know the number of host bits, you can calculate the number of host IP addresses in the subnet. Next, if you know the number of subnet bits (using classful addressing concepts) and you know that only one subnet mask is used throughout the network, you can also calculate the number of subnets in the network. The formulas just require that you know the powers of 2:

Hosts in the subnet: $2^H - 2$, where H is the number of host bits.

Subnets in the network: 2^S, where S is the number of subnet bits. Only use this formula if only one mask is used throughout the network.

> **Note**
>
> Chapter 11's section "Choose the Mask" details many concepts related to masks, including comments about this assumption of one mask throughout a single Class A, B, or C network.

The sizes of the parts of IPv4 addresses can also be calculated. The math is basic, but the concepts are important. Keeping in mind that IPv4 addresses are 32 bits long, the two parts with classless addressing must add up to 32 (P + H = 32), and with classful addressing, the three parts must add up to 32 (N + S + H = 32). Figure 13-8 shows the relationships.

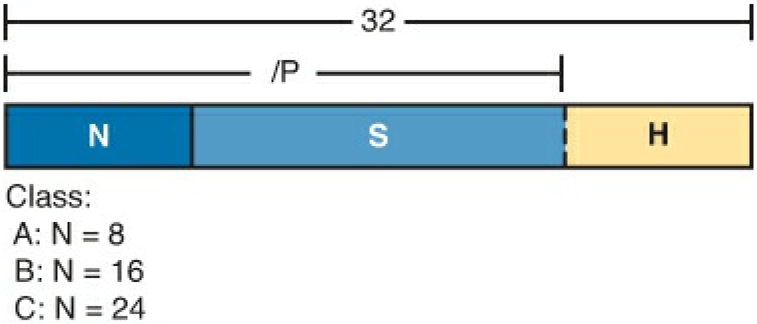


Figure 13-8. Relationship Between /P, N, S, and H

You often begin with an IP address and mask, both when answering questions on the CCENT and CCNA exams and when examining problems that occur in real networks. Based on the information in this chapter and earlier chapters, you should be able to find all the information in Figure 13-8 and then calculate the number of hosts/subnet and the number of subnets in the network. For reference, the following process spells out the steps:

Step 1. Convert the mask to prefix format (/P) as needed. (See the earlier section "Practice Converting Subnet Masks" for review.)

Step 2. Determine N based on the class. (See Chapter 12, "Analyzing Classful IPv4 Networks," for review.)

Step 3. Calculate S = P − N.

Step 4. Calculate H = 32 − P.

Step 5. Calculate hosts/subnet: $2^H - 2$.

Step 6. Calculate number of subnet: 2^S.

For example, consider the case of IP address 8.1.4.5 with mask 255.255.0.0. Following the process:

Step 1. 255.255.0.0 = /16, so P=16.

Step 2. 8.1.4.5 is in the range 1–126 in the first octet, so it is Class A; so N=8.

Step 3. S = P − N = 16 − 8 = 8.

Step 4. H = 32 − P = 32 − 16 = 16.

Step 5. $2^{16} - 2$ = 65,534 hosts/subnet.

Step 6. 2^8 = 256 subnets.

Figure 13-9 shows a visual analysis of the same problem.

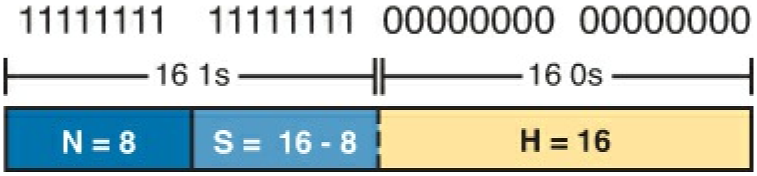


Figure 13-9. Visual Representation of Problem: 8.1.4.5, 255.255.0.0

For another example, consider address 200.1.1.1, mask 255.255.255.252. Following the process:

Step 1. 255.255.255.252 = /30, so P=30.

Step 2. 200.1.1.1 is in the range 192–223 in the first octet, so it is Class C; so N=24.

Step 3. S = P − N = 30 − 24 = 6.

Step 4. H = 32 − P = 32 − 30 = 2.

Step 5. $2^2 - 2$ = 2 hosts/subnet

Step 6. 2^6 = 64 subnets.

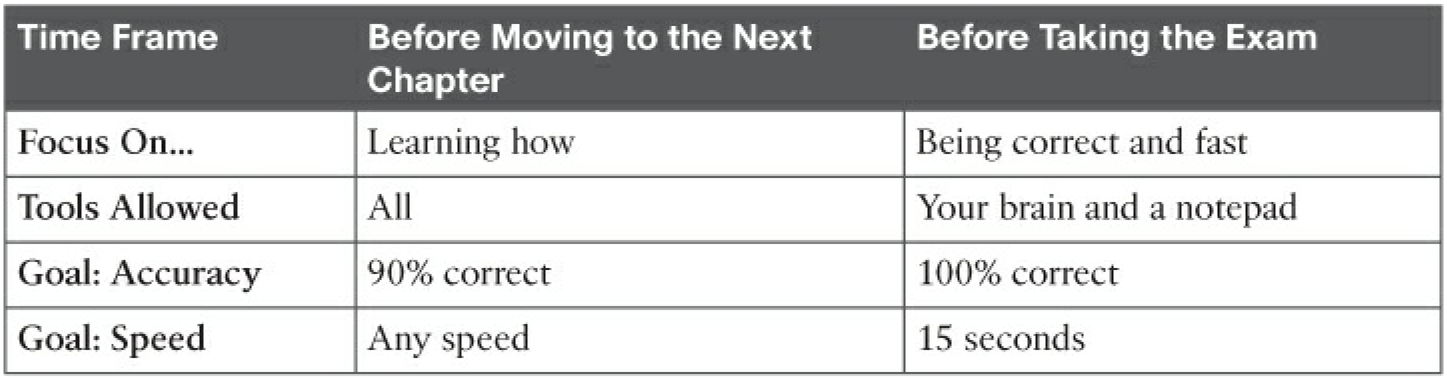
This example uses a popular mask for serial links, because serial links only require two host addresses, and the mask supports only two host addresses.

Practice Analyzing Subnet Masks

Before moving to the next chapter, practice until you get the right answer most of the time, but use any tools you want and take all the time you need. Then, you can move on with your reading.

However, before taking the exam, practice until you master the topics in this chapter and can move pretty fast. As for time, you should be able to find the entire answer—the size of the three parts, plus the formulas to calculate the number of subnets and hosts—in around 15 seconds. Table 13-9 summarizes the key concepts and suggestions for this two-phase approach.

Table 13-9. Goals: To Keep Reading and to Take the Exam



Time Frame	Before Moving to the Next Chapter	Before Taking the Exam
Focus On...	Learning how	Being correct and fast
Tools Allowed	All	Your brain and a notepad
Goal: Accuracy	90% correct	100% correct
Goal: Speed	Any speed	15 seconds

On a piece of scratch paper, answer the following questions. In each case:

- Determine the structure of the addresses in each subnet based on the class and mask, using classful IP addressing concepts. In other words, find the size of the network, subnet, and host parts of the addresses.
- Calculate the number of hosts in the subnet.
- Calculate the number of subnets in the network, assuming that the same mask is used throughout.

1. 8.1.4.5, 255.255.254.0

2. 130.4.102.1, 255.255.255.0
3. 199.1.1.100, 255.255.255.0
4. 130.4.102.1, 255.255.252.0
5. 199.1.1.100, 255.255.255.224

The answers are listed in the section "Answers to Earlier Practice Problems," later in this chapter.

For additional practice analyzing subnet masks, consider the following:

- DVD Appendix E, "Practice for Chapter 13: Analyzing Subnet Masks," has some additional practice problems listed. This section also includes explanations as to how to find the answer to each problem.
- DVD Appendix F, "Practice for Chapter 14: Analyzing Existing Subnets," has another 25 practice problems related to this chapter. Although Appendix E focuses on the topics in this chapter, the problems in Appendix E and Appendix F both begin with an IP address and mask. So, Appendix F also includes commentary and answers for items such as the number of network, subnet, and host bits, and other topics related to this chapter.
- Create your own problems. Many subnet calculators show the number of network, subnet, and host bits when you type in an IP address and mask, so make up an IP address and mask on paper, and then find N, S, and H. Then, to check your work, use any subnet calculator. Most subnet calculators list the class and network ID.

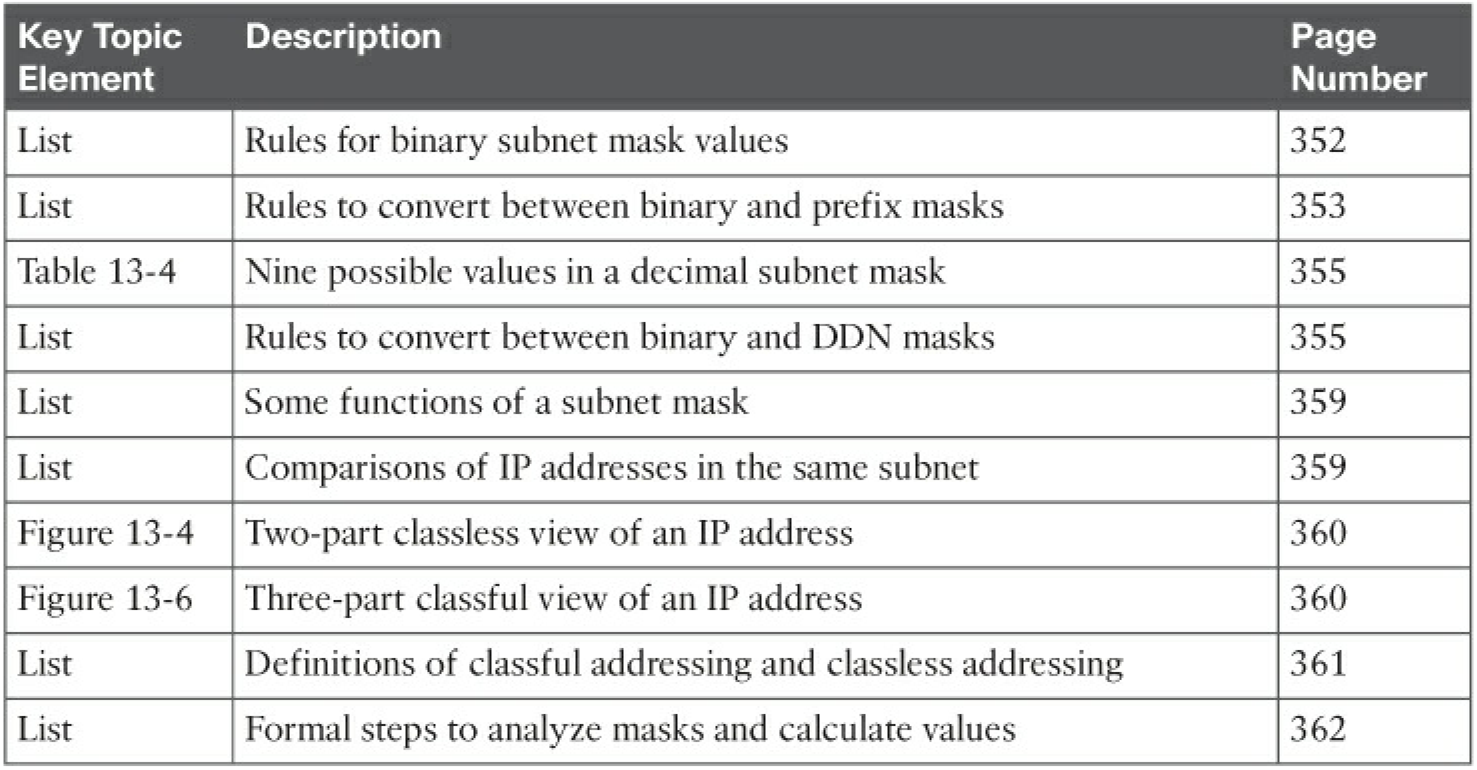
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 13-10 lists these key topics and where each is discussed.

Key Topic

Table 13-10. Key Topics for Chapter 13



Key Topic Element	Description	Page Number
List	Rules for binary subnet mask values	352
List	Rules to convert between binary and prefix masks	353
Table 13-4	Nine possible values in a decimal subnet mask	355
List	Rules to convert between binary and DDN masks	355
List	Some functions of a subnet mask	359
List	Comparisons of IP addresses in the same subnet	359
Figure 13-4	Two-part classless view of an IP address	360
Figure 13-6	Three-part classful view of an IP address	360
List	Definitions of classful addressing and classless addressing	361
List	Formal steps to analyze masks and calculate values	362

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists for you to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

- binary mask
- dotted-decimal notation (DDN)
- decimal mask
- prefix mask
- slash mask
- CIDR mask
- classful addressing
- classless addressing

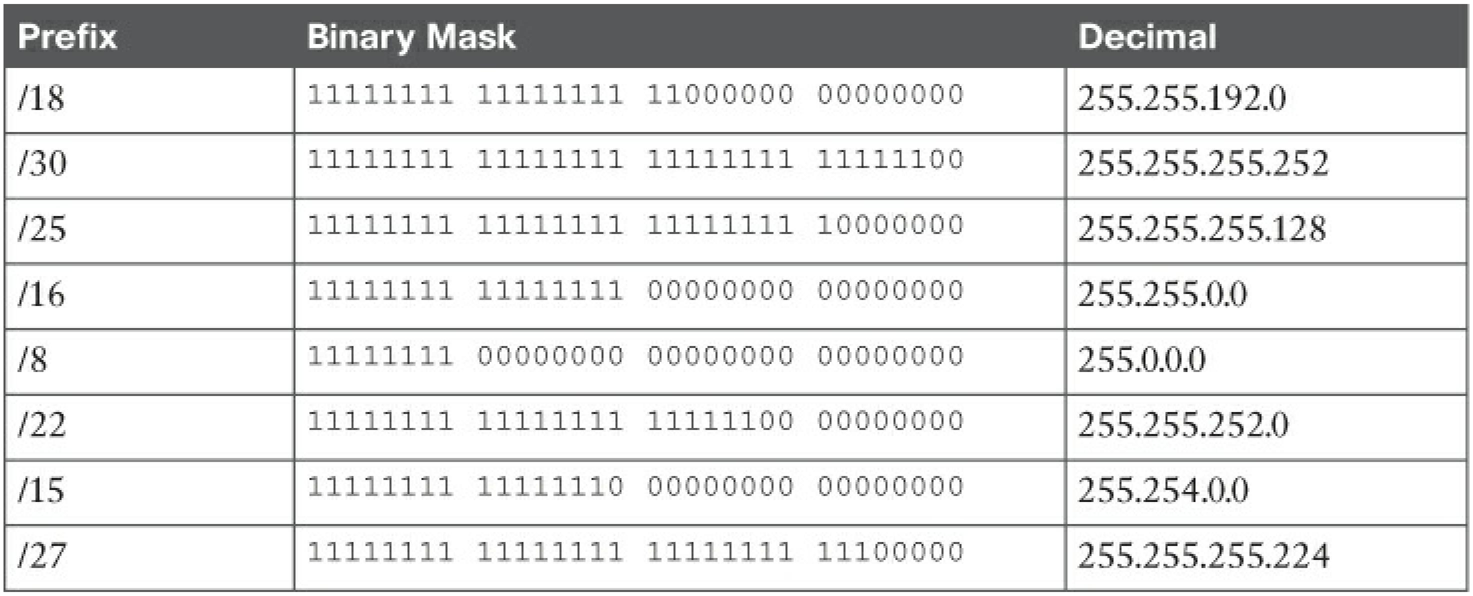
Practice

If you have not done so already, practice converting and analyzing subnet masks as discussed in this chapter. Refer to the earlier sections "Practice Converting Subnet Masks" and "Practice Analyzing Subnet Masks" for suggestions.

Answers to Earlier Practice Problems

Table 13-8, shown earlier, listed several practice problems for converting subnet masks; Table 13-11 lists the answers.

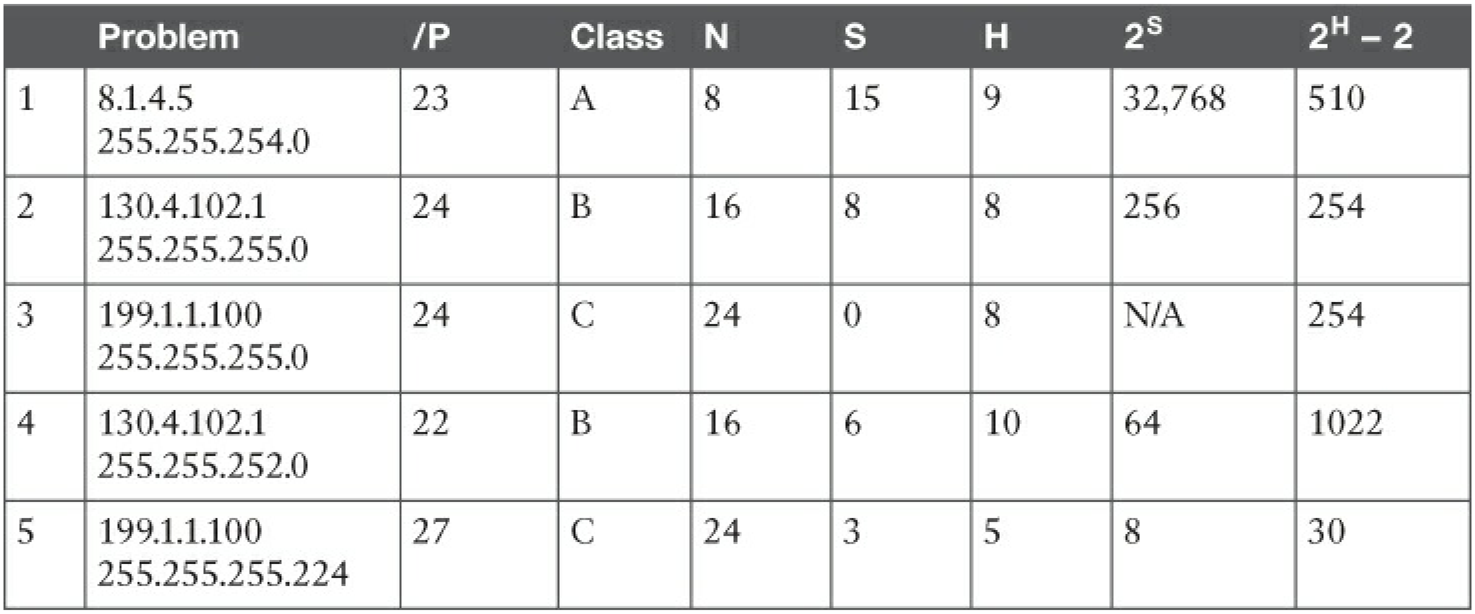
Table 13-11. Answers to Problems in Table 13-8



Prefix	Binary Mask	Decimal
/18	11111111 11111111 11000000 00000000	255.255.192.0
/30	11111111 11111111 11111111 11111100	255.255.255.252
/25	11111111 11111111 11111111 10000000	255.255.255.128
/16	11111111 11111111 00000000 00000000	255.255.0.0
/8	11111111 00000000 00000000 00000000	255.0.0.0
/22	11111111 11111111 11111100 00000000	255.255.252.0
/15	11111111 11111110 00000000 00000000	255.254.0.0
/27	11111111 11111111 11111111 11100000	255.255.255.224

Table 13-12 lists the answers to the practice problems from the earlier section "Practice Analyzing Subnet Masks."

Table 13-12. Answers to Problems from Earlier in the Chapter



	Problem	/P	Class	N	S	H	2^S	$2^H - 2$
1	8.1.4.5 255.255.254.0	23	A	8	15	9	32,768	510
2	130.4.102.1 255.255.255.0	24	B	16	8	8	256	254
3	199.1.1.100 255.255.255.0	24	C	24	0	8	N/A	254
4	130.4.102.1 255.255.252.0	22	B	16	6	10	64	1022
5	199.1.1.100 255.255.255.224	27	C	24	3	5	8	30

The following list reviews the problems:

1. For 8.1.4.5, the first octet (8) is in the 1–126 range, so it is a Class A address, with 8 network bits. Mask 255.255.254.0 converts to /23, so P – N = 15, for 15 subnet bits. H can be found by subtracting /P (23) from 32, for 9 host bits.
2. 130.4.102.1 is in the 128–191 range in the first octet, making it a Class B address, with N = 16 bits. 255.255.255.0 converts to /24, so the number of subnet bits is 24 – 16 = 8. With 24 prefix bits, the number of host bits is 32 – 24 = 8.
3. The third problem purposely shows a case where the mask does not create a subnet part of the address. The address, 199.1.1.100, has a first octet between 192 and 223, making it a Class C address with 24 network bits. The prefix version of the mask is /24, so the number of subnet bits is 24 – 24 = 0. The number of host bits is 32 minus the prefix length (24), for a total of 8 host bits. So in this case, the mask shows that the network engineer is using the default mask, which creates no subnet bits and no subnets.
4. With the same address as the second problem, 130.4.102.1 is a Class B address with N = 16 bits. This problem uses a different mask, 255.255.252.0, which converts to /22. This makes the number of subnet bits 22 – 16 = 6. With 22 prefix bits, the number of host bits is 32 – 22 = 10.
5. With the same address as the third problem, 199.1.1.100 is a Class C address with N = 24 bits. This problem uses a different mask, 255.255.255.224, which converts to /27. This makes the number of subnet bits 27 – 24 = 3. With 27 prefix bits, the number of host bits is 32 – 27 = 5.

Chapter 14. Analyzing Existing Subnets

This chapter covers the following exam topics:

Troubleshooting

Troubleshoot and correct common problems associated with IP addressing and host configurations

Often, a networking task begins with the discovery of the IP address and mask used by some host. Then, to understand how the internetwork routes packets to that host, you must find key pieces of information about the subnet, specifically:

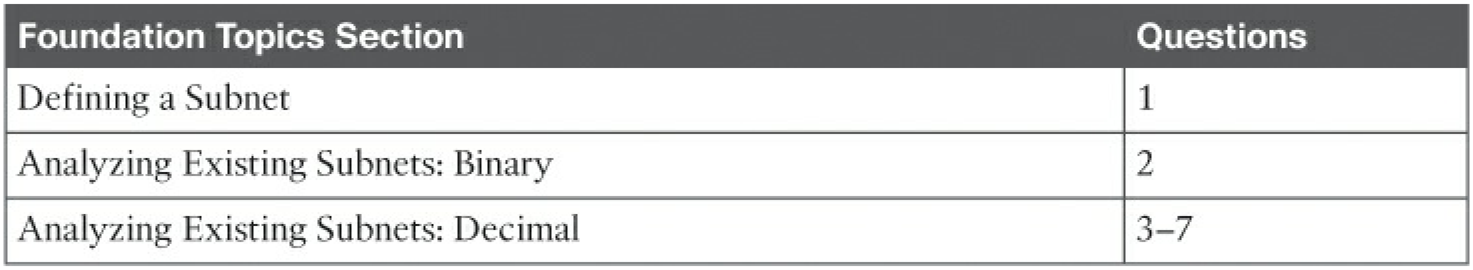
- Subnet ID
- Subnet broadcast address
- Subnet's range of usable unicast IP addresses

This chapter discusses the concepts and math to take a known IP address and mask, and then fully describe a subnet by finding the values in this list. These specific tasks might well be the most important IP skills in the entire IP addressing and subnetting topics in this book, because these tasks might be the most commonly used tasks when operating and troubleshooting real networks.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 14-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Defining a Subnet	1
Analyzing Existing Subnets: Binary	2
Analyzing Existing Subnets: Decimal	3–7

1. When thinking about an IP address using classful addressing rules, an address can have three parts: network, subnet, and host. If you examined all the addresses in one subnet, in binary, which of the following answers correctly states which of the three parts of the addresses will be equal among all addresses? Pick the best answer.
   - **a.** Network part only
   - **b.** Subnet part only
   - **c.** Host part only
   - **d.** Network and subnet parts
   - **e.** Subnet and host parts
2. Which of the following statements are true regarding the binary subnet ID, subnet broadcast address, and host IP address values in any single subnet? (Choose two.)
   - **a.** The host part of the broadcast address is all binary 0s.
   - **b.** The host part of the subnet ID is all binary 0s.
   - **c.** The host part of a usable IP address can have all binary 1s.
   - **d.** The host part of any usable IP address must not be all binary 0s.
3. Which of the following is the resident subnet ID for IP address 10.7.99.133/24?
   - **a.** 10.0.0.0
   - **b.** 10.7.0.0
   - **c.** 10.7.99.0
   - **d.** 10.7.99.128
4. Which of the following is the resident subnet for IP address 192.168.44.97/30?
   - **a.** 192.168.44.0
   - **b.** 192.168.44.64
   - **c.** 192.168.44.96
   - **d.** 192.168.44.128
5. Which of the following is the subnet broadcast address for the subnet in which IP address 172.31.77.201/27 resides?
   - **a.** 172.31.201.255
   - **b.** 172.31.255.255

- **c.** 172.31.77.223
- **d.** 172.31.77.207

6. A fellow engineer tells you to configure the DHCP server to lease the last 100 usable IP addresses in subnet 10.1.4.0/23. Which of the following IP addresses could be leased as a result of your new configuration?

- **a.** 10.1.4.156
- **b.** 10.1.4.254
- **c.** 10.1.5.200
- **d.** 10.1.7.200
- **e.** 10.1.255.200

7. A fellow engineer tells you to configure the DHCP server to lease the first 20 usable IP addresses in subnet 192.168.9.96/27. Which of the following IP addresses could be leased as a result of your new configuration?

- **a.** 192.168.9.126
- **b.** 192.168.9.110
- **c.** 192.168.9.1
- **d.** 192.168.9.119

Answers to the "Do I Know This Already?" quiz:

1 D **2** B and D **3** C **4** C **5** C **6** C **7** B

Foundation Topics

Defining a Subnet

An IP subnet is a subset of a classful network, created by choice of some network engineer. However, that engineer cannot pick just any arbitrary subset of addresses; instead, the engineer must follow certain rules, such as the following:

- The subnet contains a set of consecutive numbers.
- The subnet holds 2^H numbers, where H is the number of host bits defined by the subnet mask.
- Two special numbers in the range cannot be used as IP addresses:
  - The first (lowest) number acts as an identifier for the subnet (*subnet ID*).
  - The last (highest) number acts as a *subnet broadcast address*.
- The remaining addresses, whose values sit between the subnet ID and subnet broadcast address, are used as *unicast IP addresses*.

This section reviews and expands the basic concepts of the subnet ID, subnet broadcast address, and range of addresses in a subnet.

An Example with Network 172.16.0.0 and Four Subnets

Imagine that you work at the customer support center, where you receive all initial calls from users who have problems with their computer. You coach the user through finding her IP address and mask: 172.16.150.41, mask 255.255.192.0. One of the first and most common tasks you will do based on that information is to find the subnet ID of the subnet in which that address resides. (In fact, this subnet ID is sometimes called the *resident subnet*, because the IP address exists in or resides in that subnet.)

Before getting into the math, examine the mask (255.255.192.0) and classful network (172.16.0.0) for a moment. From the mask, based on what you learned in Chapter 13, "Analyzing Subnet Masks," you can find the structure of the addresses in the subnet, including the number of host and subnet bits. That analysis tells you that 2 subnet bits exist, meaning that there should be four (2^2) subnets. (If these concepts are not yet clear, review Chapter 13's section "How Masks Define the Format of

Addresses.") Figure 14-1 shows the idea.

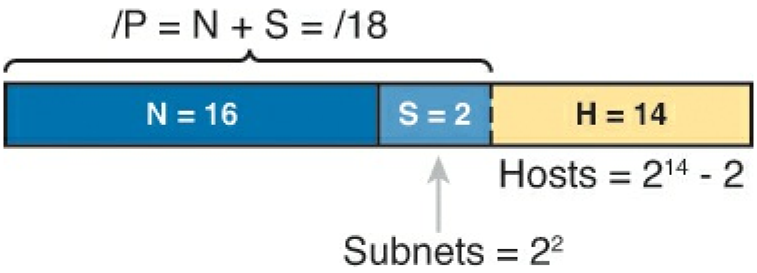

/P = N + S = /18
N = 16
S = 2
H = 14
Hosts = 2^14 - 2
Subnets = 2^2

Figure 14-1. Address Structure: Class B Network, /18 Mask

> **Note**
>
> This chapter, like the others in this part of the book, assume that one mask is used throughout an entire classful network.

Because each subnet uses a single mask, all subnets of this single IP network must be the same size, because all subnets have the same structure. In this example, all four subnets will have the structure shown in the figure, so all four subnets will have 2^{14} – 2 host addresses.

Next, consider the big picture of what happens with this example subnet design: The one Class B network now has four subnets of equal size. Conceptually, if you represent the entire Class B network as a number line, each subnet consumes one-fourth of the number line, as shown in Figure 14-2. Each subnet has a subnet ID—the numerically lowest number in the subnet—so it sits on the left of the subnet. And each subnet has a subnet broadcast address—the numerically highest number in the subnet—so it sits on the right side of the subnet.

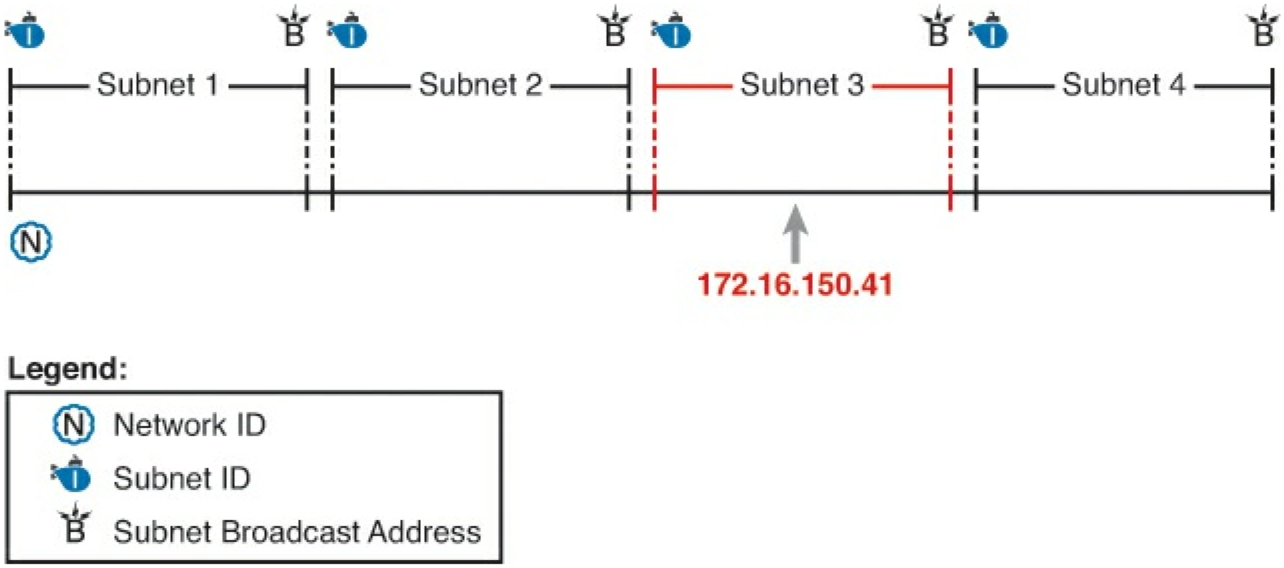

Subnet 1
Subnet 2
Subnet 3
Subnet 4
N
172.16.150.41
Legend:
N Network ID
I Subnet ID
B Subnet Broadcast Address

Figure 14-2. Network 172.16.0.0, Divided into Four Equal Subnets

The rest of this chapter focuses on how to take one IP address and mask and discover the details about that one subnet in which the address resides. In other words, you see how to find the resident subnet of an IP address. Again, using IP address 172.16.150.41 and mask 255.255.192.0 as an example, Figure 14-3 shows the resident subnet, along with the subnet ID and subnet broadcast address that bracket the subnet.

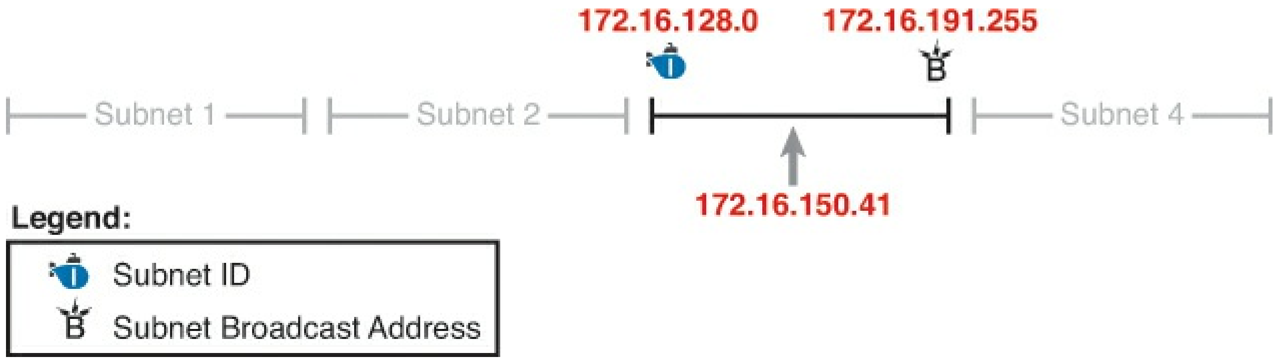

172.16.128.0
172.16.191.255
Subnet 1
Subnet 2
Subnet 4
172.16.150.41
Legend:
I Subnet ID
B Subnet Broadcast Address

Figure 14-3. Resident Subnet for 172.16.150.41, 255.255.192.0

Subnet ID Concepts

A subnet ID is simply a number used to succinctly represent a subnet. When listed along with its matching subnet mask, the subnet ID identifies the subnet and can be used to derive the subnet broadcast address and range of addresses in the subnet. Rather than having to write down all these details about a subnet, you simply need to write down the subnet ID and mask, and you have enough information to fully describe the subnet.

The subnet ID appears in many places, but it is seen most often in IP routing tables. For example, when an engineer configures a router with its IP address and mask, the router calculates the subnet ID and puts a route into its routing table for that subnet. The router typically then advertises the subnet ID/mask combination to neighboring routers with some IP routing protocol. Eventually, all the routers in an enterprise learn about the subnet—again using the subnet ID and subnet mask combination—and display it in their routing tables. (You can display the contents of a router's IP routing table using the **show ip route** command.)

Unfortunately, the terminology related to subnets can sometimes cause problems. First, the terms *subnet ID*, *subnet number*, and *subnet address* are synonyms. Additionally, people sometimes simply say *subnet* when referring to both the idea of a subnet and the number that is used as the subnet ID. When talking about routing, people sometimes use the term *prefix* instead of *subnet*. The term *prefix* refers to the same idea as *subnet*; it just uses terminology from the classless addressing way to describe IP addresses, as discussed in Chapter 13's section "Classless and Classful Addressing."

The biggest terminology confusion arises between the terms *network* and *subnet*. In the real world, people often use these terms synonymously, and that is perfectly reasonable in some cases. In other cases, the specific meaning of these terms, and their differences, matter to what is being discussed.

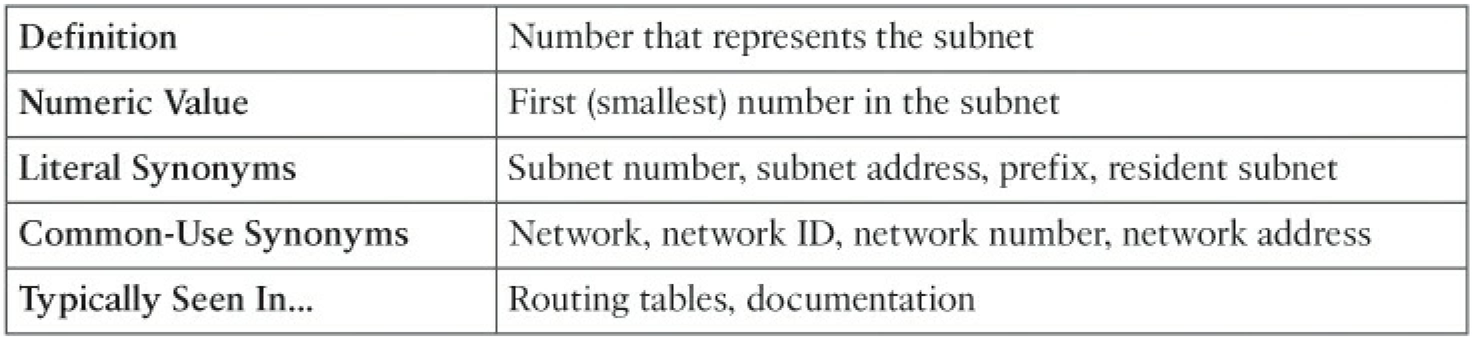
For example, people often might say, "What is the network ID?" when they really want to know the subnet ID. In another case, they might want to know the Class A, B, or C network ID. So, when one engineer asks something like, "What's the net ID for 172.16.150.41 slash 18?" use the context to figure out whether he wants the literal classful network ID (172.16.0.0, in this case) or the literal subnet ID (172.16.128.0, in this case).

For the exams, be ready to notice when the terms *subnet* and *network* are used, and then use the context to figure out the specific meaning of the term in that case.

Table 14-2 summarizes the key facts about the subnet ID, along with the possible synonyms, for easier review and study.

Key Topic

Table 14-2. Summary of Subnet ID Key Facts



Definition	Number that represents the subnet
Numeric Value	First (smallest) number in the subnet
Literal Synonyms	Subnet number, subnet address, prefix, resident subnet
Common-Use Synonyms	Network, network ID, network number, network address
Typically Seen In...	Routing tables, documentation

Subnet Broadcast Address

The subnet broadcast address has two main roles: to be used as a destination IP address for the purpose of sending packets to all hosts in the subnet, and as a means to find the high end of the range of addresses in a subnet.

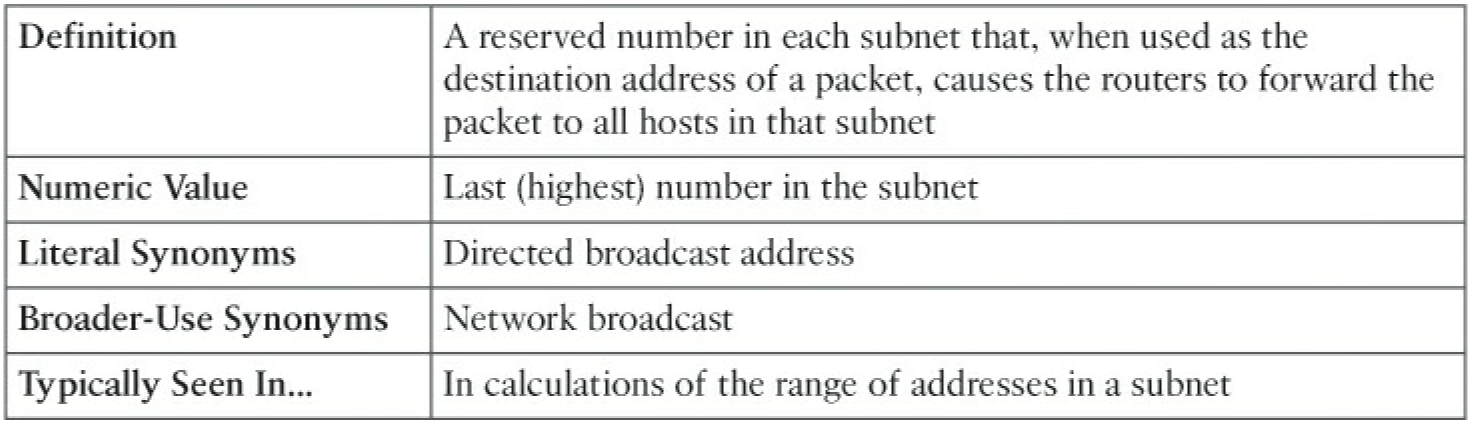
The original purpose for the subnet broadcast address was to give hosts a way to send one packet to all hosts in a subnet, and to do so efficiently. For example, a host in subnet A could send a packet with a destination address of subnet B's subnet broadcast address. The routers would forward this one packet just like a packet sent to a host in subnet B. After the packet arrives at the router connected to subnet B, that last router would then forward the packet to all hosts in subnet B, typically by encapsulating the packet in a data link layer broadcast frame. As a result, all hosts in host B's subnet would receive a copy of the packet.

The subnet broadcast address also helps you find the range of addresses in a subnet, because the broadcast address is the last (highest) number in a subnet's range of addresses. To find the low end of the range, calculate the subnet ID; to find the high end of the range, calculate the subnet broadcast address.

Table 14-3 summarizes the key facts about the subnet broadcast address, along with the possible synonyms, for easier review and study.

Key Topic

Table 14-3. Summary of Subnet Broadcast Address Key Facts



Definition	A reserved number in each subnet that, when used as the destination address of a packet, causes the routers to forward the packet to all hosts in that subnet
Numeric Value	Last (highest) number in the subnet
Literal Synonyms	Directed broadcast address
Broader-Use Synonyms	Network broadcast
Typically Seen In...	In calculations of the range of addresses in a subnet

Range of Usable Addresses

The engineers implementing an IP internetwork need to know the range of unicast IP addresses in each subnet. Before you can plan which addresses to use as statically assigned IP addresses, which to configure to be leased by the DHCP server, and which to reserve for later use, you need to know the range of usable addresses.

To find the range of usable IP addresses in a subnet, first find the subnet ID and the subnet broadcast address. Then, just add 1 to the fourth octet of the subnet ID to get the first (lowest) usable address, and subtract 1 from the fourth octet of the subnet broadcast address to get the last (highest) usable address in the subnet.

For example, Figure 14-3 showed subnet ID 172.16.128.0, mask /18. The first usable address is simply 1 more than the subnet ID (in this case, 172.16.128.1). That same figure showed a subnet broadcast address of 172.16.191.255, so the last usable address is 1 less, or 172.16.191.254.

Now that this section has described the concepts behind the numbers that collectively define a subnet, the rest of this chapter focuses on the math used to find these values.

Analyzing Existing Subnets: Binary

What does it mean to "analyze a subnet"? For this book, it means that you should be able to start with an IP address and mask and then define key facts about the subnet in which that address resides. Specifically, that means discovering the subnet ID, subnet broadcast address, and range of addresses. The analysis can also include the calculation of the number of addresses in the subnet as discussed in Chapter 13, but this chapter does not review those concepts.

Many methods exist to calculate the details about a subnet based on the address/mask. This section begins by discussing some calculations that use binary math, with the next section showing alternatives that use only decimal math. Although many people prefer the decimal method for going fast on the exams, the binary calculations ultimately give you a better understanding of IPv4 addressing. In particular, if you plan to move on to attain Cisco certifications beyond CCNA, you should take the time to understand the binary methods discussed in this section, even if you use the decimal methods for the exams.

Finding the Subnet ID: Binary

To start this section that uses binary, first consider a simple decimal math problem. The problem: Find the smallest three-digit decimal number that begins with 4. The answer, of course, is 400. And although most people would not have to break down the logic into steps, you know that 0 is the lowest-value digit you can use for any digit in a decimal number. You know that the first digit must be a 4, and the number is a three-digit number, so you just use the lowest value (0) for the last two digits, and find the answer: 400.

This same concept, applied to binary IP addresses, gives you the subnet ID. You have seen all the related concepts in other chapters, so if you already intuitively know how to find the subnet ID in binary, great! If not, the following key facts should help you see the logic:

- All numbers in the subnet (subnet ID, subnet broadcast address, and all usable IP addresses) have the same value in the prefix part of the numbers.
- The subnet ID is the lowest numeric value in the subnet, so its host part, in binary, is all 0s.

To find the subnet ID in binary, you take the IP address in binary and change all host bits to binary 0. To do so, you need to convert the IP address to binary. You also need to identify the prefix and host bits, which can be easily done by converting the mask (as needed) to prefix format. (Note that Appendix A, "Numeric Reference Tables," includes a decimal-binary conversion table.) Figure 14-4 shows the idea, using the same address/mask as in the earlier examples in this chapter: 172.16.150.41, mask /18.

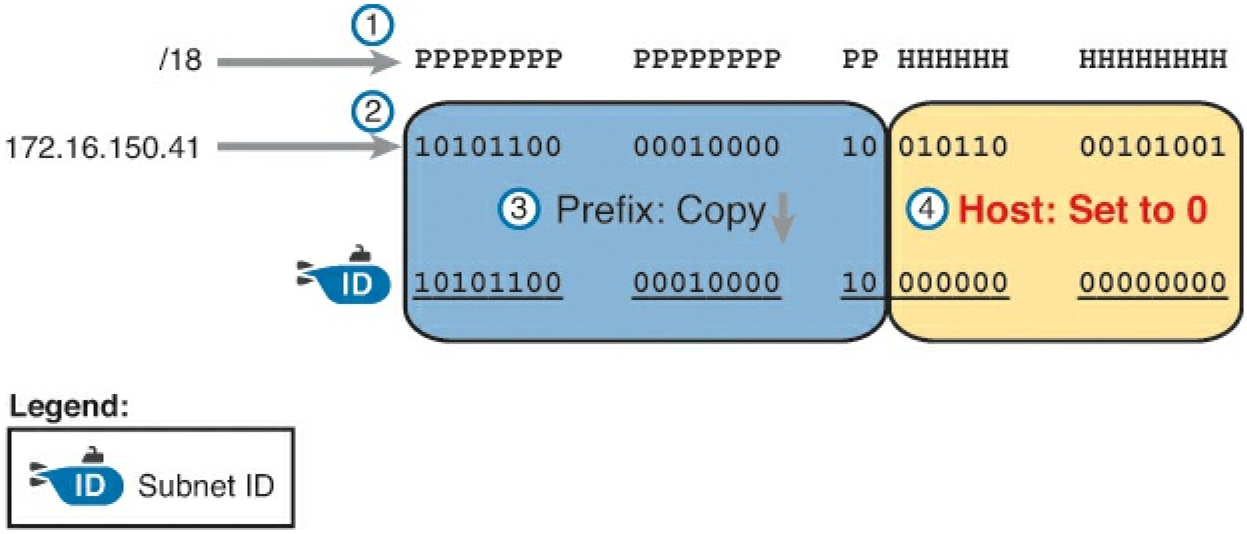

①
/18
PPPPPPPP PPPPPPPP PP HHHHHH HHHHHHHH
②
172.16.150.41
10101100 00010000 10 010110 00101001
③ Prefix: Copy
④ Host: Set to 0
ID
10101100 00010000 10 000000 00000000
Legend:
ID Subnet ID

Figure 14-4. Binary Concept: Convert the IP Address to the Subnet ID

Starting at the top of Figure 14-4, the format of the IP address is represented with 18 prefix (P) and 14 host (H) bits in the mask (Step 1). The second row (Step 2) shows the binary version of the IP address, converted from the dotted-decimal notation (DDN) value 172.16.150.41. (If you have not used the conversion table in Appendix A yet, it might be useful to double-check the conversion of all four octets based on the table.)

The next two steps show the action to copy the IP address's prefix bits (Step 3) and give the host bits a value of binary 0 (Step 4). This resulting number is the subnet ID (in binary).

The last step, not shown in Figure 14-4, is to convert the subnet ID from binary to decimal. This book shows that conversion as a separate step, in Figure 14-5, mainly because many people make a mistake at this step in the process. When converting a 32-bit number (like an IP address or IP subnet ID) back to an IPv4 DDN, you must follow this rule:

> Convert 8 bits at a time from binary to decimal, regardless of the line between the prefix and host parts of the number.

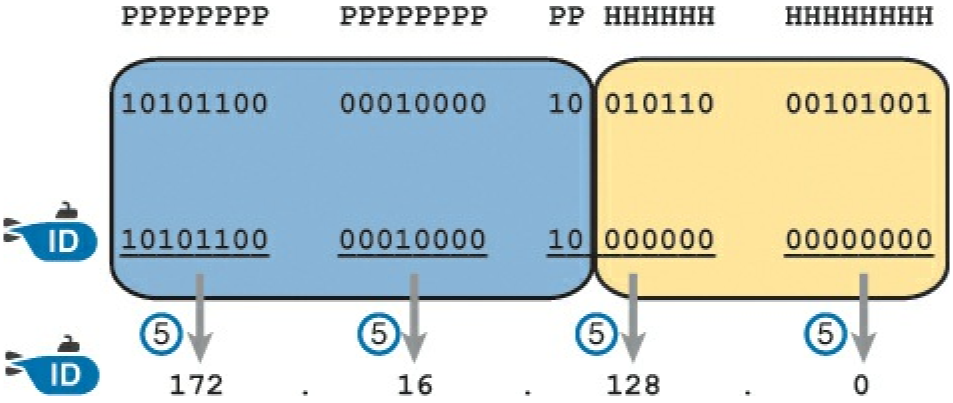

PPPPPPPP PPPPPPPP PP HHHHHH HHHHHHHH
10101100 00010000 10 010110 00101001
ID
10101100 00010000 10 000000 00000000
⑤ ⑤ ⑤ ⑤
ID
172 . 16 . 128 . 0

Figure 14-5. Converting the Subnet ID from Binary to DDN

Figure 14-5 shows this final step. Note that the third octet (the third set of 8 bits) has 2 bits in the prefix and 6 bits in the host part of the number, but the conversion occurs for all 8 bits.

> **Note**
>
> You can do the numeric conversions in Figures 14-4 and 14-5 by relying on the conversion table in Appendix A. To convert from DDN to binary, for each octet, find the decimal value in the table and then write down the 8-bit binary equivalent. To convert from binary back to DDN, for each octet of 8 bits, find the matching binary entry in the table and write down the corresponding decimal value. For example, 172 converts to binary 10101100, and 00010000 converts to decimal 16.

Finding the Subnet Broadcast Address: Binary

Finding the subnet broadcast address uses a similar process. To find the subnet broadcast address, use the same binary process used to find the subnet ID, but instead of setting all the host bits to the lowest value (all binary 0s), set the host part to the highest value (all binary 1s). Figure 14-6 shows the concept.

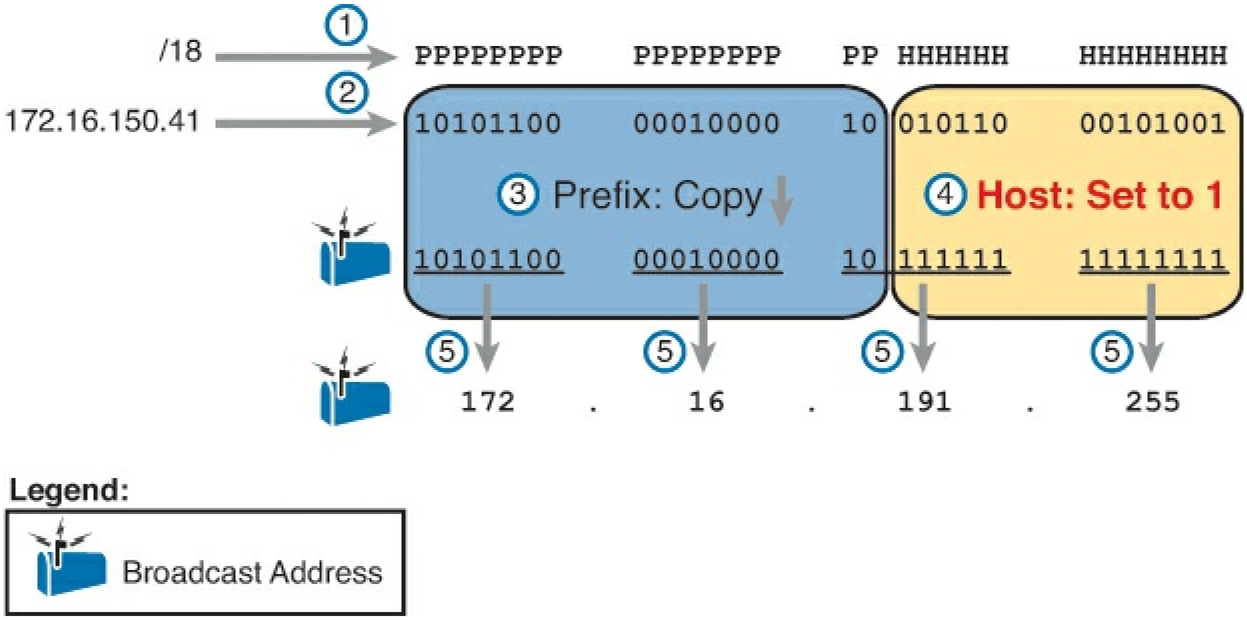


Figure 14-6. Finding a Subnet Broadcast Address: Binary

The process in Figure 14-6 demonstrates the same first three steps shown Figure 14-4. Specifically, it shows the identification of the prefix and host bits (Step 1), the results of converting the IP address 172.16.150.41 to binary (Step 2), and the copying of the prefix bits (first 18 bits, in this case). The difference occurs in the host bits on the right, changing all host bits (the last 14, in this case) to the largest possible value (all binary 1s). The final step converts the 32-bit subnet broadcast address to DDN format. Also, remember that with any conversion from DDN to binary or vice versa, the process always converts using 8 bits at a time. In particular, in this case, the entire third octet of binary 10111111 is converted back to decimal 191.

Binary Practice Problems

Figures 14-4 and 14-5 demonstrate a process to find the subnet ID using binary math. The following process summarizes those steps in written form for easier reference and practice:

Key Topic

Step 1. Convert the mask to prefix format to find the length of the prefix (/P) and the length of the host part (32 – P).

Step 2. Convert the IP address to its 32-bit binary equivalent.

Step 3. Copy the prefix bits of the IP address.

Step 4. Write down 0s for the host bits.

Step 5. Convert the resulting 32-bit number, 8 bits at a time, back to decimal.

The process to find the subnet broadcast address is exactly the same, except in Step 4, you set the bits to 1s, as seen in Figure 14-6.

Take a few moments and run through the following five practice problems on scratch paper. In each case, find both the subnet ID and subnet broadcast address. Also, record the prefix style mask:

1. 8.1.4.5, 255.255.0.0
2. 130.4.102.1, 255.255.255.0
3. 199.1.1.100, 255.255.255.0
4. 130.4.102.1, 255.255.252.0
5. 199.1.1.100, 255.255.255.224

Tables 14-4 through 14-8 show the results for the five different examples. The tables show the host bits in bold, and they include the binary version of the address and mask and the binary version of the subnet ID and subnet broadcast address.

Table 14-4. Subnet Analysis for Subnet with Address 8.1.4.5, Mask 255.255.0.0

Prefix Length	/16	11111111 11111111 **00000000 00000000**
Address	8.1.4.5	00001000 00000001 **00000100 00000101**
Subnet ID	8.1.0.0	00001000 00000001 **00000000 00000000**
Broadcast Address	8.1.255.255	00001000 00000001 **11111111 11111111**

Table 14-5. Subnet Analysis for Subnet with Address 130.4.102.1, Mask 255.255.255.0

Prefix Length	/24	11111111 11111111 11111111 **00000000**
Address	130.4.102.1	10000010 00000100 01100110 **00000001**
Subnet ID	130.4.102.0	10000010 00000100 01100110 **00000000**
Broadcast Address	130.4.102.255	10000010 00000100 01100110 **11111111**

Table 14-6. Subnet Analysis for Subnet with Address 199.1.1.100, Mask 255.255.255.0

Prefix Length	/24	11111111 11111111 11111111 **00000000**
Address	199.1.1.100	11000111 00000001 00000001 **01100100**
Subnet ID	199.1.1.0	11000111 00000001 00000001 **00000000**
Broadcast Address	199.1.1.255	11000111 00000001 00000001 **11111111**

Table 14-7. Subnet Analysis for Subnet with Address 130.4.102.1, Mask 255.255.252.0

Prefix Length	/22	11111111 11111111 111111**00 00000000**
Address	130.4.102.1	10000010 00000100 011001**10 00000001**
Subnet ID	130.4.100.0	10000010 00000100 011001**00 00000000**
Broadcast Address	130.4.103.255	10000010 00000100 011001**11 11111111**

Table 14-8. Subnet Analysis for Subnet with Address 199.1.1.100, Mask 255.255.255.224

Prefix Length	/27	11111111 11111111 11111111 111**00000**
Address	199.1.1.100	11000111 00000001 00000001 011**00100**
Subnet ID	199.1.1.96	11000111 00000001 00000001 011**00000**
Broadcast Address	199.1.1.127	11000111 00000001 00000001 011**11111**

Shortcut for the Binary Process

The binary process described in this section so far requires that all four octets be converted to binary and then back to decimal. However, you can easily predict the results in at least three of the four octets, based on the DDN mask. You can then avoid the binary math in all but one octet and reduce the number of binary conversions you need to do.

First, consider an octet, and that octet only, whose DDN mask value is 255. The mask value of 255 converts to binary 11111111, which means that all 8 bits are prefix bits. Thinking through the steps in the process, at Step 2, you convert the address to some number. At Step 3, you copy the number. At Step 4, you convert the same 8-bit number back to decimal. All you did in those three steps, in this one octet, is convert from decimal to binary and convert the same number back to the same decimal value!

In short, the subnet ID (and subnet broadcast address) are equal to the IP address in octets for which the mask is 255.

For example, the resident subnet ID for 172.16.150.41, mask 255.255.192.0 is 172.16.128.0. The first two mask octets are 255. Rather than think about the binary math, you could just start by copying the address's value in those two octets: 172.16.

Another shortcut exists for octets whose DDN mask value is decimal 0, or binary 00000000. With a decimal mask value of 0, the math always results in a decimal 0 for the subnet ID, no matter the beginning value in the IP address. Specifically, just look at Steps 4 and 5 in this case: At Step 4, you would write down 8 binary 0s, and at Step 5, convert 00000000 back to decimal 0.

The following revised process steps take these two shortcuts into account. However, when the mask is neither 0 nor 255, the process requires the same conversions. At most, you have to do only one octet of the conversions. To find the subnet ID, apply the logic in these steps for each of the four octets:

Key Topic

Step 1. If the mask = 255, copy the decimal IP address for that octet.

Step 2. If the mask = 0, write down a decimal 0 for that octet.

Step 3. If the mask is neither 0 nor 255 in this octet, use the same binary logic as shown in the section "Finding the Subnet ID: Binary," earlier in this chapter.

Figure 14-7 shows an example of this process, again using 172.16.150.41, 255.255.192.0.

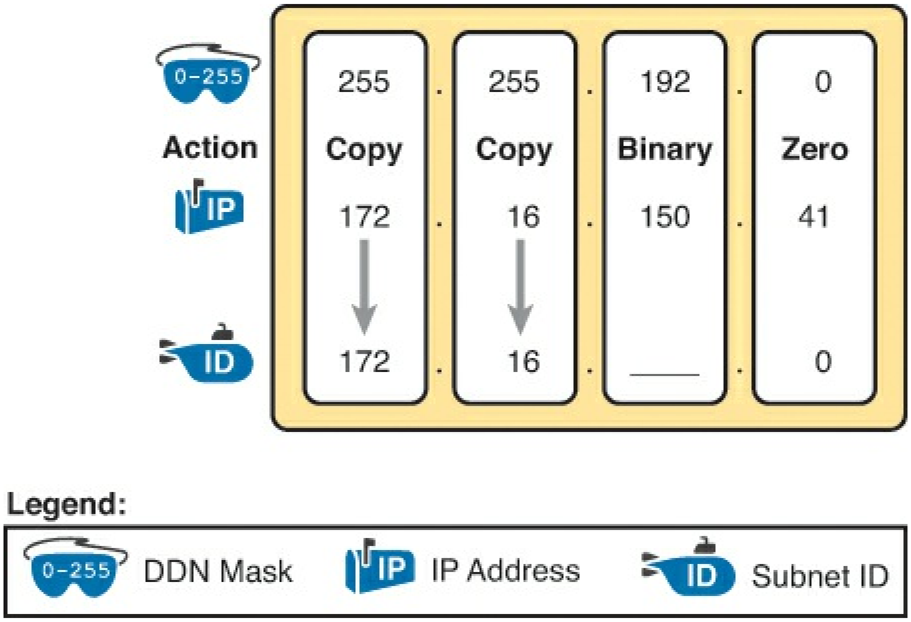


Figure 14-7. Binary Shortcut Example

A similar shortcut exists when finding the subnet broadcast address. For DDN mask octets equal to decimal 0, set the decimal subnet broadcast address value to 255 instead of 0, as noted in the following list:

Key Topic

Step 1. If the mask = 255, copy the decimal IP address for that octet.

Step 2. If the mask = 0, write down a decimal 255 for that octet.

Step 3. If the mask is neither 0 nor 255 in this octet, use the same binary logic as shown in the section "Finding the Subnet Broadcast Address: Binary," earlier in this chapter.

Brief Note About Boolean Math

So far, this chapter has described how humans can use binary math to find the subnet ID and subnet broadcast address. However, computers typically use an entirely different binary process to find the same values, using a branch of mathematics called *Boolean Algebra*. Computers already store the IP address and mask in binary form, so they do not have to do any conversions to and from decimal. Then, certain Boolean operations allow the computers to calculate the subnet ID and subnet broadcast address with just a few CPU instructions.

You do not need to know Boolean math to have a good understanding of IP subnetting. However, in case you are interested, computers use the following Boolean logic to find the subnet ID and subnet broadcast address, respectively:

> Perform a *Boolean AND* of the IP address and mask. This process converts all host bits to binary 0.
>
> Invert the mask, and then perform a *Boolean OR* of the IP address and inverted subnet mask. This process converts all host bits to binary 1s.

Finding the Range of Addresses

Finding the range of usable addresses in a subnet, after you know the subnet ID and subnet broadcast address, requires only simple addition and subtraction. To find the first (lowest) usable IP address in the subnet, simply add 1 to the fourth octet of the subnet ID. To find the last (highest) usable IP address, simply subtract 1 from the fourth octet of the subnet broadcast address.

Analyzing Existing Subnets: Decimal

Analyzing existing subnets using the binary process works well. However, some of the math takes time for most people, particularly the decimal-binary conversions. And you need to do the math quickly for the Cisco CCENT and CCNA exams. For the exams, you really should be able to take an IP address and mask, and calculate the subnet ID and range of usable addresses within about 15 seconds. When using binary methods, most people require a lot of practice to be able to find these answers, even when using the abbreviated binary process.

This section discusses how to find the subnet ID and subnet broadcast address using only decimal math. Most people can find the answers more quickly using this process, at least after a little practice, as compared with the binary process. However, the decimal process does not tell you anything about the meaning behind the math. So, if you have not read the earlier section "Analyzing Existing Subnets: Binary," it is worthwhile to read it for the sake of understanding subnetting. This section focuses on getting the right answer using a method that, after you have practiced, should be faster.

Analysis with Easy Masks

With three easy subnet masks in particular, finding the subnet ID and subnet broadcast address requires only easy logic and literally no math. Three easy masks exist:

255.0.0.0
255.255.0.0
255.255.255.0

These easy masks have only 255 and 0 in decimal. In comparison, difficult masks have one octet that has neither a 255 nor a 0 in the mask, which makes the logic more challenging.

> **Note**
>
> The terms *easy mask* and *difficult mask* are terms created for use in this book to describe the masks and the level of difficulty when working with each.

When the problem uses an easy mask, you can quickly find the subnet ID based on the IP address and mask in DDN format. Just use the following process for each of the four octets to find the subnet ID:

Step 1. If the mask octet = 255, copy the decimal IP address.

Step 2. If the mask octet = 0, write a decimal 0.

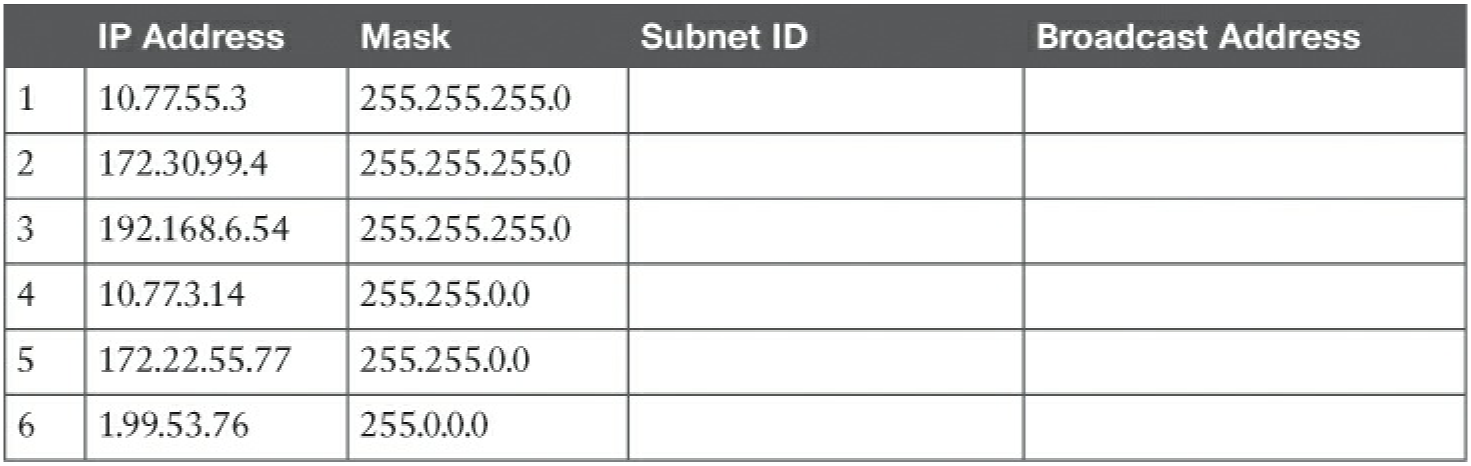
A similar simple process exists to find the subnet broadcast address, as follows:

Step 1. If the mask octet = 255, copy the decimal IP address.

Step 2. If the mask octet = 0, write a decimal 255.

Before moving to the next section, take some time to fill in the blanks in Table 14-9. Check your answers against Table 14-14 in the section "Answers to Earlier Practice Problems," later in this chapter. Complete the table by listing the subnet ID and subnet broadcast address.

Table 14-9. Practice Problems: Find Subnet ID and Broadcast, Easy Masks



	IP Address	Mask	Subnet ID	Broadcast Address
1	10.77.55.3	255.255.255.0		
2	172.30.99.4	255.255.255.0		
3	192.168.6.54	255.255.255.0		
4	10.77.3.14	255.255.0.0		
5	172.22.55.77	255.255.0.0		
6	1.99.53.76	255.0.0.0		

Predictability in the Interesting Octet

Although three masks are easier to work with (255.0.0.0, 255.255.0.0, and 255.255.255.0), the rest make the decimal math a little more difficult, so we call these masks difficult masks. With difficult masks, one octet is neither a 0 nor a 255. The math in the other three octets is easy and boring, so this book calls the one octet with the more difficult math the *interesting octet*.

If you take some time to think about different problems and focus on the interesting octet, you will begin to see a pattern. This section takes you through that examination so that you can learn how to predict the pattern, in decimal, and find the subnet ID.

First, the subnet ID value has a predictable decimal value because of the assumption that a single subnet mask is used for all subnets of a single classful network. The chapters in this part of the book assume that, for a given classful network, the design engineer chooses to use a single subnet mask for all subnets. (Refer to Chapter 11's section "One Size Subnet Fits All—Or Not" for more details.)

To see that predictability, consider some planning information written down by a network engineer, as shown in Figure 14-8. The figure shows four different masks the engineer is considering using in an IPv4 network, along with Class B network 172.16.0.0. The figure shows the third-octet values for the subnet IDs that would be created when using mask 255.255.255.128, 255.255.255.192, 255.255.255.224, and 255.255.255.240, from top to bottom in the figure.

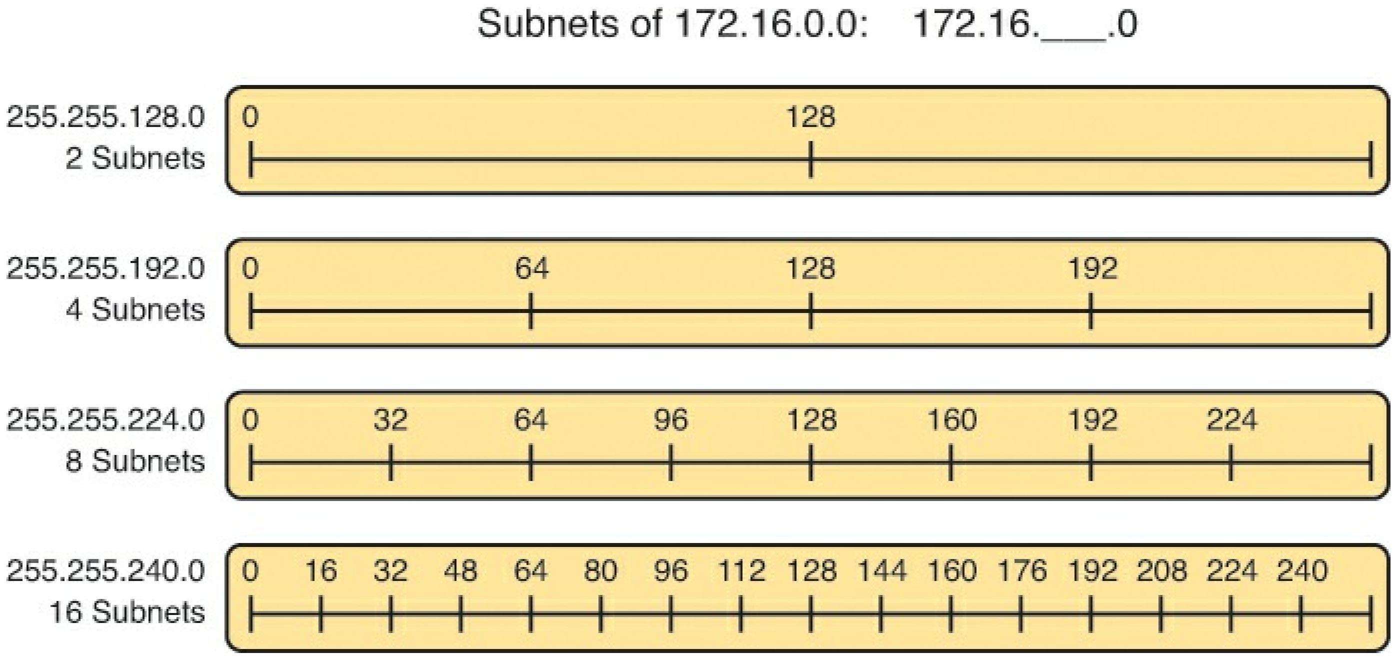


Figure 14-8. Numeric Patterns in the Interesting Octet

First, to explain the figure further, look at the top row of the figure. If the engineer uses 255.255.255.128 as the mask, the mask creates two subnets, with subnet IDs 172.16.0.0 and 172.16.128.0. If the engineer uses mask 255.255.255.192, the mask creates four subnets, with subnet IDs 172.16.0.0, 172.16.64.0.0, 172.16.128.0, and 172.16.192.0.

If you take the time to look at the figure, the patterns become obvious. In this case:

Mask: 255.255.255.128 Pattern: Multiples of 128
Mask: 255.255.255.192 Pattern: Multiples of 64
Mask: 255.255.255.224 Pattern: Multiples of 32
Mask: 255.255.255.240 Pattern: Multiples of 16

To find the subnet ID, you just need a way to figure out what the pattern is. If you start with an IP address and mask, just find the subnet ID closest to the IP address, without going over, as discussed in the next section.

Finding the Subnet ID: Difficult Masks

The following written process lists all the steps for find the subnet ID, using only decimal math. This process adds to the earlier process used with easy masks. For each octet:

Key Topic

Step 1. If the mask octet = 255, copy the decimal IP address.
Step 2. If the mask octet = 0, write a decimal 0.
Step 3. If the mask is neither, refer to this octet as the *interesting octet*:
  A. Calculate the *magic number* as 256 − mask.
  B. Set the subnet ID's value to the multiple of the magic number that is closest to the IP address without going over.

The process uses two new terms created for this book: *magic number* and *interesting octet*. The term *interesting octet* refers to the octet identified at Step 3 in the process; in other words, it is the octet with the mask that is neither 255 nor 0. Step 3A then uses the term *magic number*, which is derived from the DDN mask. Conceptually, the magic number is the number you add to one subnet ID to get the next subnet ID in order, as shown in Figure 14-8. Numerically, it can be found by subtracting the DDN mask's value, in the interesting octet, from 256, as mentioned in Step 3A.

The best way to learn this process is to see it happen. In fact, if you can, stop reading now, use the DVD accompanying this book, and watch the videos about finding the subnet ID with a difficult mask. These videos demonstrate this process. You can also use the examples on the next few pages that show the process being used on paper. Then, follow the practice opportunities outlined in the section "Practice Analyzing Existing Subnets," later in this chapter.

Resident Subnet Example 1

For example, consider the requirement to find the resident subnet for IP address 130.4.102.1, mask 255.255.240.0. The process does not require you to think about prefix bits versus host bits, convert the mask, think about the mask in binary, or convert the IP address to and from binary. Instead, for each of the four octets, choose an action based on the value in the mask. Figure 14-9 shows the results; the circled numbers in the figure refer to the step numbers in the written process to find the subnet ID, as listed in the previous few pages.

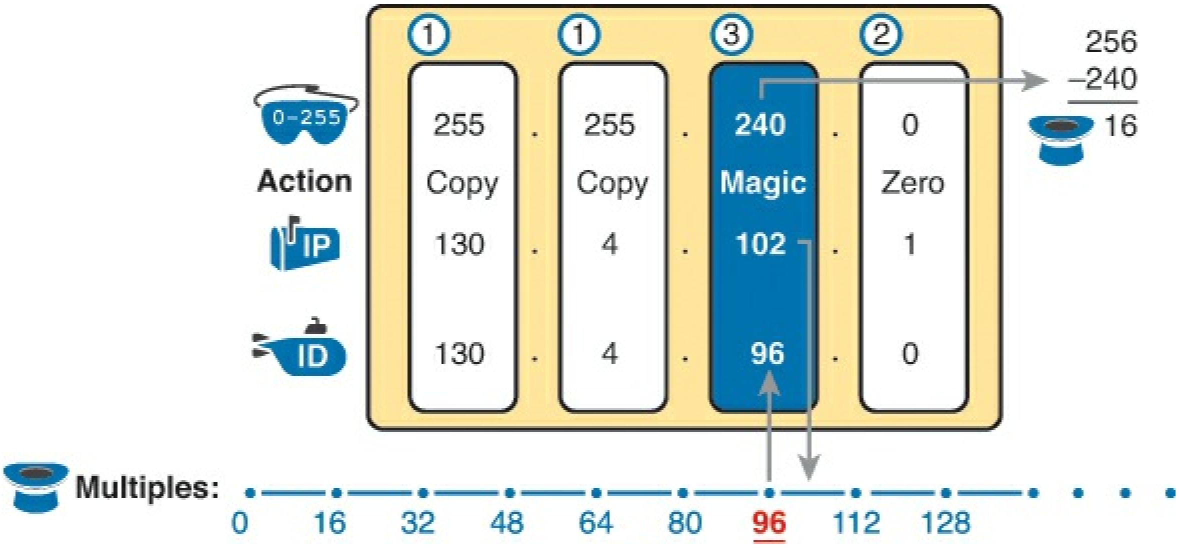


Figure 14-9. Find the Subnet ID: 130.4.102.1, 255.255.240.0

First, examine the three uninteresting octets (1, 2, and 4, in this example). The process keys on the mask, and the first two octets have a mask value of 255, so simply copy the IP address to the place where you intend to write down the subnet ID. The fourth octet has a mask value 0, so write down a 0 for the fourth octet of the subnet ID.

The most challenging logic occurs in the interesting octet, which is the third octet in this example, because of the mask value 240 in that octet. For this octet, Step 3A asks you to calculate the magic number as 256 – mask. That means you take the mask's value in the interesting octet (240, in this case) and subtract it from 256: 256 – 240 = 16. The subnet ID's value in this octet must be a multiple of decimal 16, in this case.

Step 3B then asks you to find the multiples of the magic number (16, in this case) and choose the one closest to the IP address without going over. Specifically, that means that you should mentally calculate the multiples of the magic number, starting at 0. (Do not forget to start at 0!) Counting, starting at 0: 0, 16, 32, 48, 64, 80, 96, 112, and so on. Then, find the multiple closest to the IP address value in this octet (102, in this case), without going over 102. So, as shown in Figure 14-9, you make the third octet's value 96 to complete the subnet ID of 130.4.96.0.

Resident Subnet Example 2

Consider another example: 192.168.5.77, mask 255.255.255.224. Figure 14-10 shows the results.

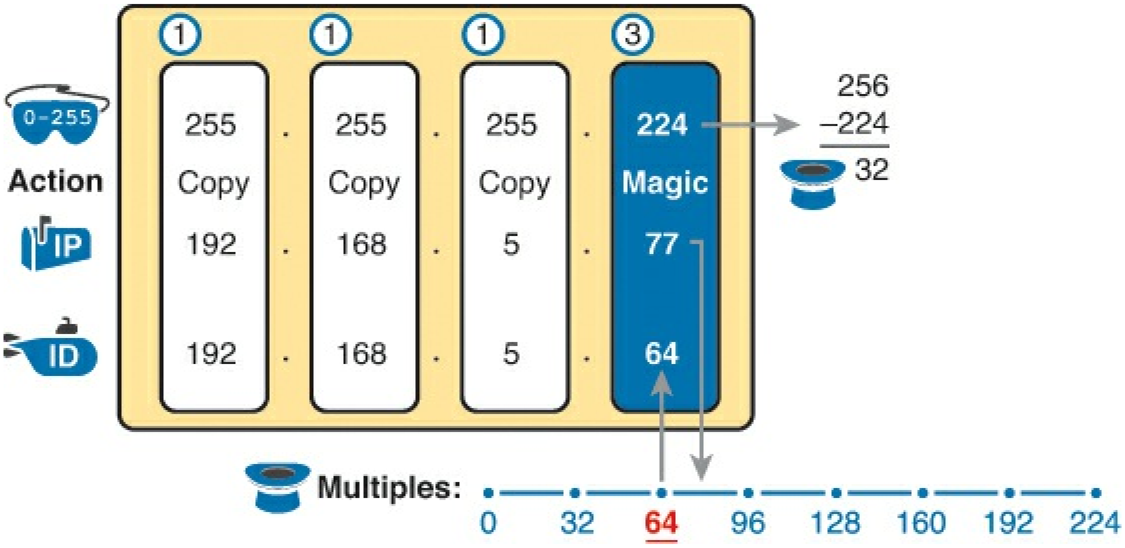


Figure 14-10. Resident Subnet for 192.168.5.77, 255.255.255.224

The three uninteresting octets (1, 2, and 3, in this case) require only a little thought. For each octet, each with a mask value of 255, just copy the IP address.

For the interesting octet, at Step 3A, the magic number is 256 − 224 = 32. The multiples of the magic number are 0, 32, 64, 96, and so on. Because the IP address value in the fourth octet is 77, in this case, the multiple must be the number closest to 77 without going over; therefore, the subnet ID ends with 64, for a value of 192.168.5.64.

Resident Subnet Practice Problems

Before moving to the next section, take some time to fill in the blanks in Table 14-10. Check your answers against Table 14-15 in the section "Answers to Earlier Practice Problems," later in this chapter. Complete the table by listing the subnet ID in each case. The text following Table 14-15 also lists explanations for each problem.

Table 14-10. Practice Problems: Find Subnet ID, Difficult Masks

Problem	IP Address	Mask	Subnet ID
1	10.77.55.3	255.248.0.0	
2	172.30.99.4	255.255.192.0	
3	192.168.6.54	255.255.255.252	
4	10.77.3.14	255.255.128.0	
5	172.22.55.77	255.255.254.0	
6	1.99.53.76	255.255.255.248	

Finding the Subnet Broadcast Address: Difficult Masks

To find a subnet's broadcast address, a similar process can be used. For simplicity, this process begins with the subnet ID, rather than the IP address. If you happen to start with an IP address instead, use the processes in this chapter to first find the subnet ID, and then use the following process to find the subnet broadcast address for that same subnet. For each octet:

Key Topic

Step 1. If the mask octet = 255, copy the subnet ID.

Step 2. If the mask octet = 0, write a 255.

Step 3. If the mask is neither, identify this octet as the *interesting octet*:

- **A.** Calculate the *magic number* as 256 − mask.
- **B.** Take the subnet ID's value, add the magic number, and subtract 1 (ID + magic − 1).

As with the similar process used to find the subnet ID, you have several options for how to best learn and internalize the process. If you can, stop reading now, use the DVD accompanying this book, and watch the videos about finding the subnet broadcast address with a difficult mask. Also, look at the examples in this section, which show the process being used on paper. Then, follow the practice opportunities outlined in the section "Additional Practice."

Subnet Broadcast Example 1

The first example continues the first example from the section "Finding the Subnet ID: Difficult Masks," earlier in this chapter, as demonstrated in Figure 14-9. That example started with the IP address/mask of 130.4.102.1, 255.255.240.0, and showed how to find subnet ID 130.4.96.0. Figure 14-11 now begins with that subnet ID and the same mask.

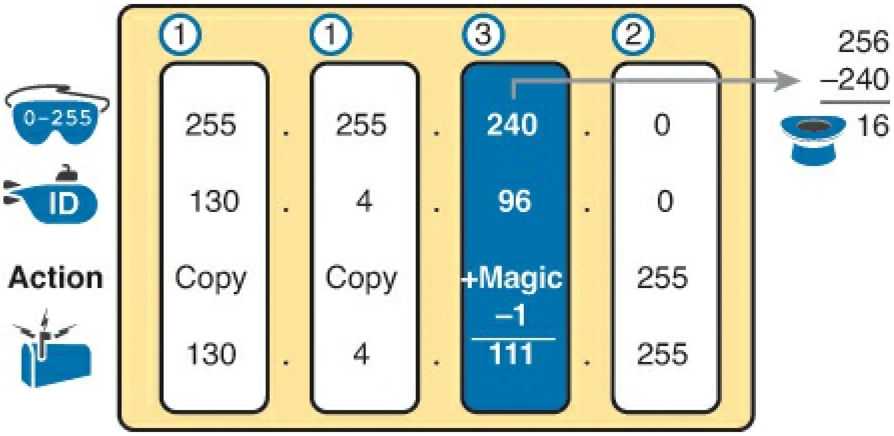


Figure 14-11. Find the Subnet Broadcast: 130.4.96.0, 255.255.240.0

First, examine the three uninteresting octets (1, 2, and 4). The process keys on the mask, and the first two octets have a mask value of 255, so simply copy the subnet ID to the place where you intend to write down the subnet broadcast address. The fourth octet has a mask value 0, so write down a 255 for the fourth octet.

The logic related to the interesting octet occurs in the third octet in this example, because of the mask value 240. First, Step 3A asks you to calculate the magic number, as 256 – mask. (If you had already calculated the subnet ID using the decimal process in this book, you should already know the magic number.) At Step 3B, you take the subnet ID's value (96), add magic (16), and subtract 1, for a total of 111. That makes the subnet broadcast address 130.4.111.255.

Subnet Broadcast Example 2

Again, this example continues an earlier example, from the section "Resident Subnet Example 2," as demonstrated in Figure 14-10. That example started with the IP address/mask of 192.168.5.77, mask 255.255.255.224 and showed how to find subnet ID 192.168.5.64. Figure 14-12 now begins with that subnet ID and the same mask.

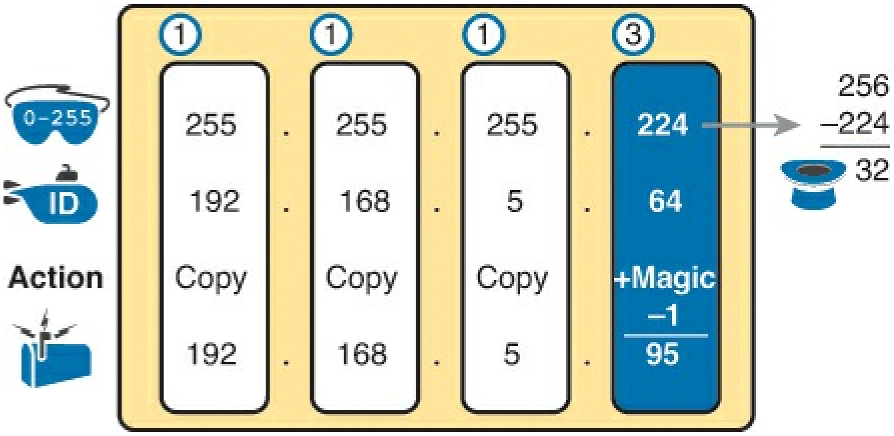


Figure 14-12. Find the Subnet Broadcast: 192.168.5.64, 255.255.255.224

First, examine the three uninteresting octets (1, 2, and 3). The process keys on the mask, and the first three octets have a mask value of 255, so simply copy the subnet ID to the place where you intend to write down the subnet broadcast address.

The interesting logic occurs in the interesting octet, the fourth octet in this example, because of the mask value 224. First, Step 3A asks you to calculate the magic number, as 256 – mask. (If you had already calculated the subnet ID, it is the same magic number, because the same mask is used.) At Step 3B, you take the subnet ID's value (64), add magic (32), and subtract 1, for a total of 95. That makes the subnet broadcast address 192.168.5.95.

Subnet Broadcast Address Practice Problems

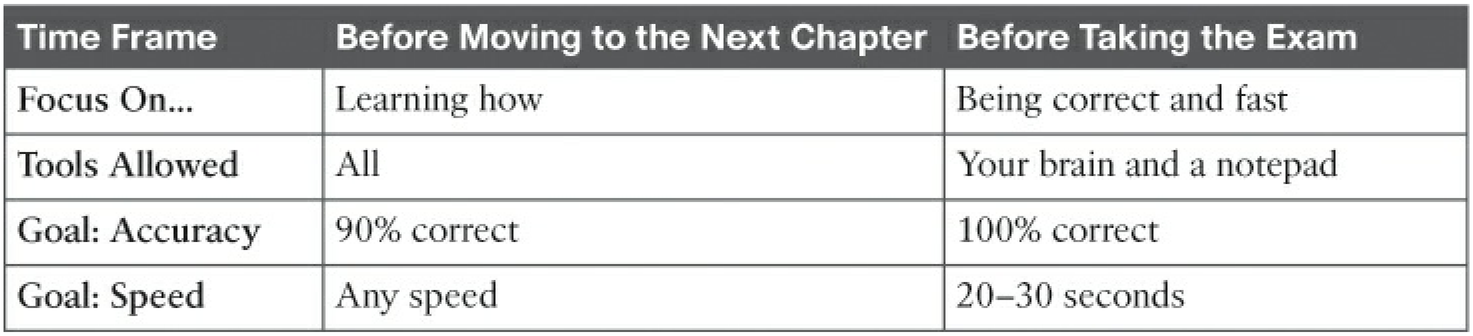
Before moving to the next section, take some time to do several practice problems on a scratch piece of paper. Go back to Table 14-10, which lists IP addresses and masks, and practice by finding the subnet broadcast address for all the problems in that table. Then check your answers against Table 14-16 in the section "Answers to Earlier Practice Problems," later in this chapter.

Practice Analyzing Existing Subnets

Before moving to the next chapter, practice until you get the right answer most of the time—but use any tools you want and take all the time you need. Then, you can move on with your reading.

However, before taking the exam, practice until you master the topics in this chapter and can move pretty fast. As for time, you should be able to find the subnet ID, based on an IP address and mask, in around 15 seconds. You should also strive to start with a subnet ID/mask, and find the broadcast address and range of addresses, in another 10–15 seconds. Table 14-11 summarizes the key concepts and suggestions for this two-phase approach.

Table 14-11. Keep-Reading and Take-Exam Goals for This Chapter's Topics



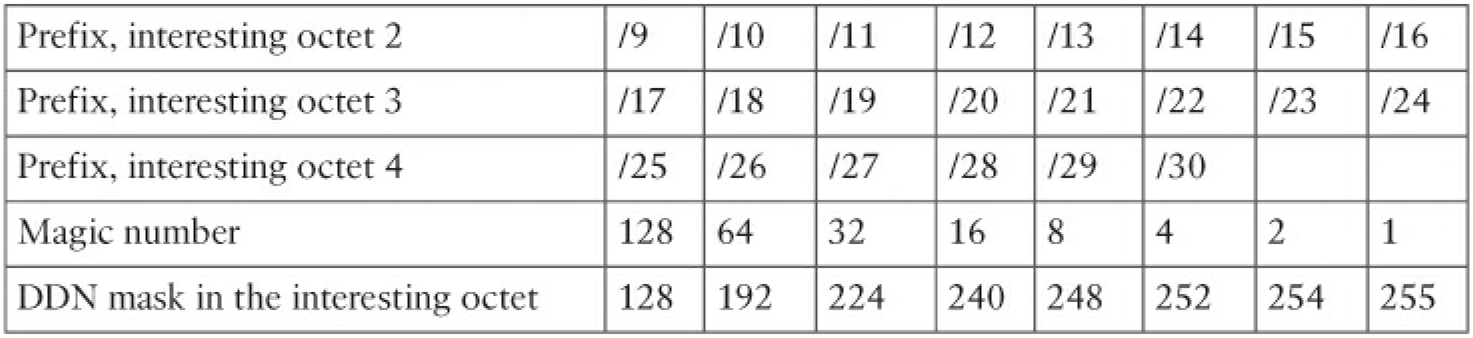
Time Frame	Before Moving to the Next Chapter	Before Taking the Exam
Focus On...	Learning how	Being correct and fast
Tools Allowed	All	Your brain and a notepad
Goal: Accuracy	90% correct	100% correct
Goal: Speed	Any speed	20–30 seconds

A Choice: Memorize or Calculate

As described in this chapter, the decimal processes to find the subnet ID and subnet broadcast address do require some calculation, including the calculation of the magic number (256 – mask). The processes also use a DDN mask, so if an exam question gives you a prefix-style mask, you need to convert to DDN format before using the process in this book.

Over the years, some people have told me they prefer to memorize a table to find the magic number. These tables could list the magic number for different DDN masks and prefix masks, so you avoid converting from the prefix mask to DDN. Table 14-12 shows an example of such a table. Feel free to ignore this table, use it, or make your own.

Table 14-12. Reference Table: DDN Mask Values, Binary Equivalent, Magic Numbers, and Prefixes



Prefix, interesting octet 2	/9	/10	/11	/12	/13	/14	/15	/16
Prefix, interesting octet 3	/17	/18	/19	/20	/21	/22	/23	/24
Prefix, interesting octet 4	/25	/26	/27	/28	/29	/30		
Magic number	128	64	32	16	8	4	2	1
DDN mask in the interesting octet	128	192	224	240	248	252	254	255

Additional Practice

This section lists several options for additional practice:

- DVD Appendix F, "Practice for Chapter 14: Analyzing Existing Subnets," has some additional practice problems. This appendix also includes explanations about how to find the answer of each problem.
- Create your own problems. Many subnet calculators list the number of network, subnet, and host bits when you type in an IP address and mask, so make up an IP address and mask on paper, and find the subnet ID and range of addresses. Then, to check your work, use any subnet calculator. (Check the author's web pages for this book, as listed in the Introduction, for some suggested calculators.)

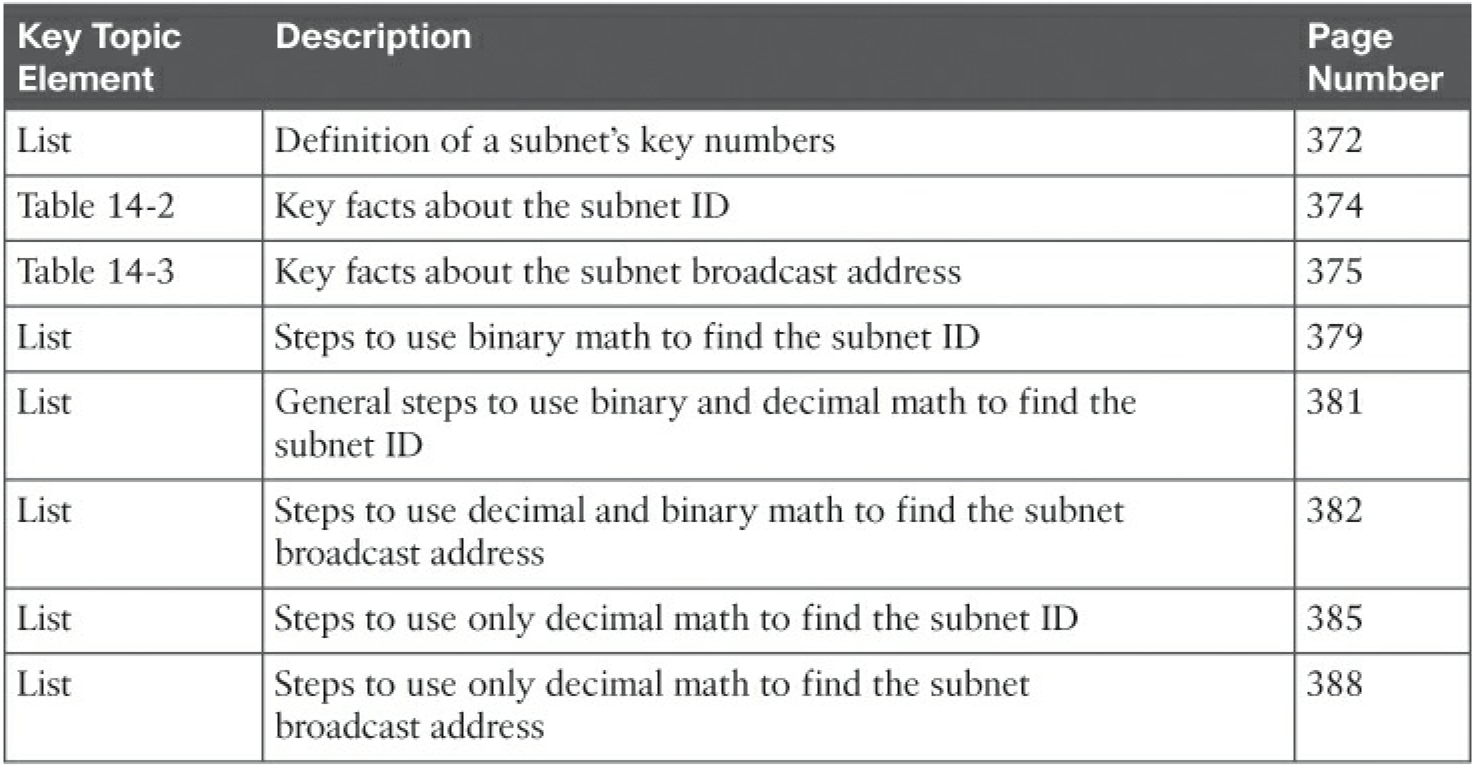
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 14-13 lists these key topics and where each is discussed.

Key Topic

Table 14-13. Key Topics for Chapter 14



Key Topic Element	Description	Page Number
List	Definition of a subnet's key numbers	372
Table 14-2	Key facts about the subnet ID	374
Table 14-3	Key facts about the subnet broadcast address	375
List	Steps to use binary math to find the subnet ID	379
List	General steps to use binary and decimal math to find the subnet ID	381
List	Steps to use decimal and binary math to find the subnet broadcast address	382
List	Steps to use only decimal math to find the subnet ID	385
List	Steps to use only decimal math to find the subnet broadcast address	388

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists for you to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

- resident subnet
- subnet ID
- subnet number
- subnet address
- subnet broadcast address

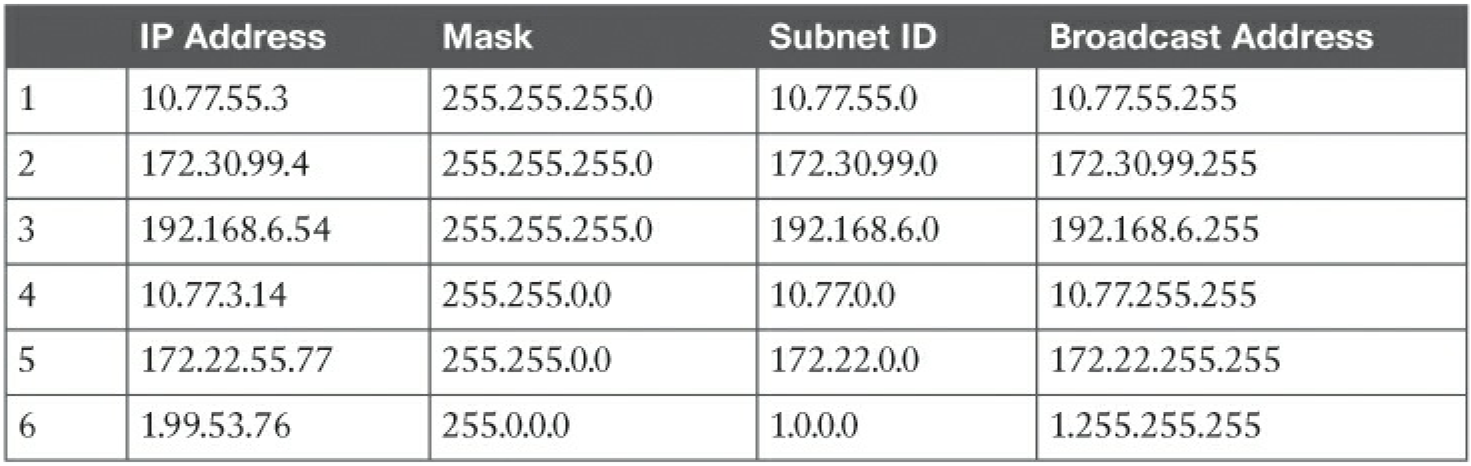
Practice

If you have not done so already, practice finding the subnet ID, range of addresses, and subnet broadcast address associated with an IP address and mask. Refer to the earlier section "Practice Analyzing Existing Subnets" for suggestions.

Answers to Earlier Practice Problems

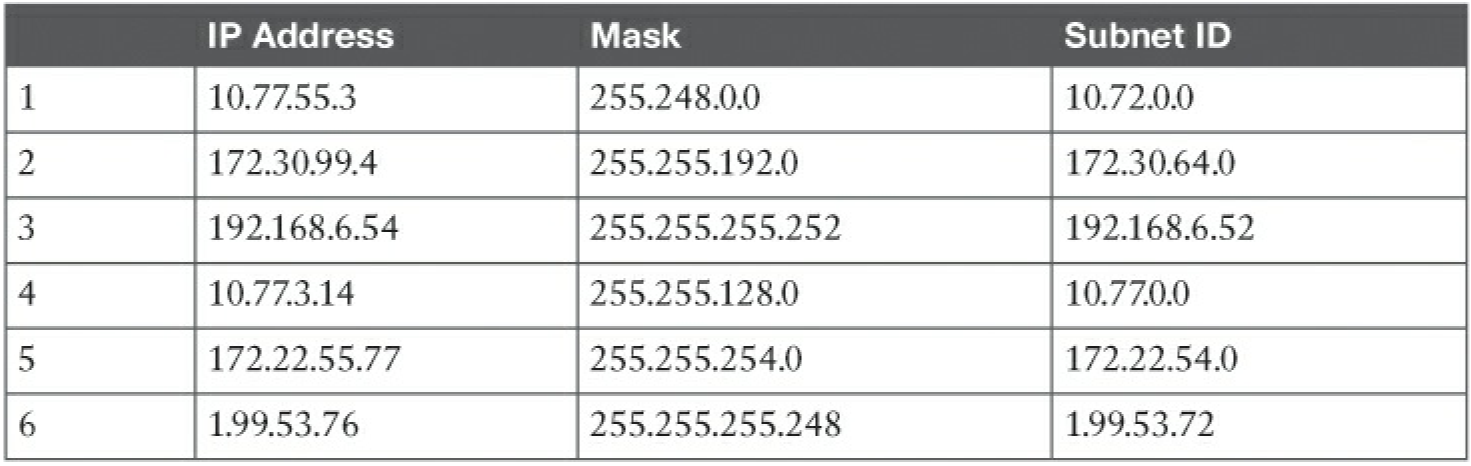
This chapter includes practice problems spread around different locations in the chapter. The answers are located in Tables 14-14, 14-15, and 14-16.

Table 14-14. Answers to Problems in Table 14-9



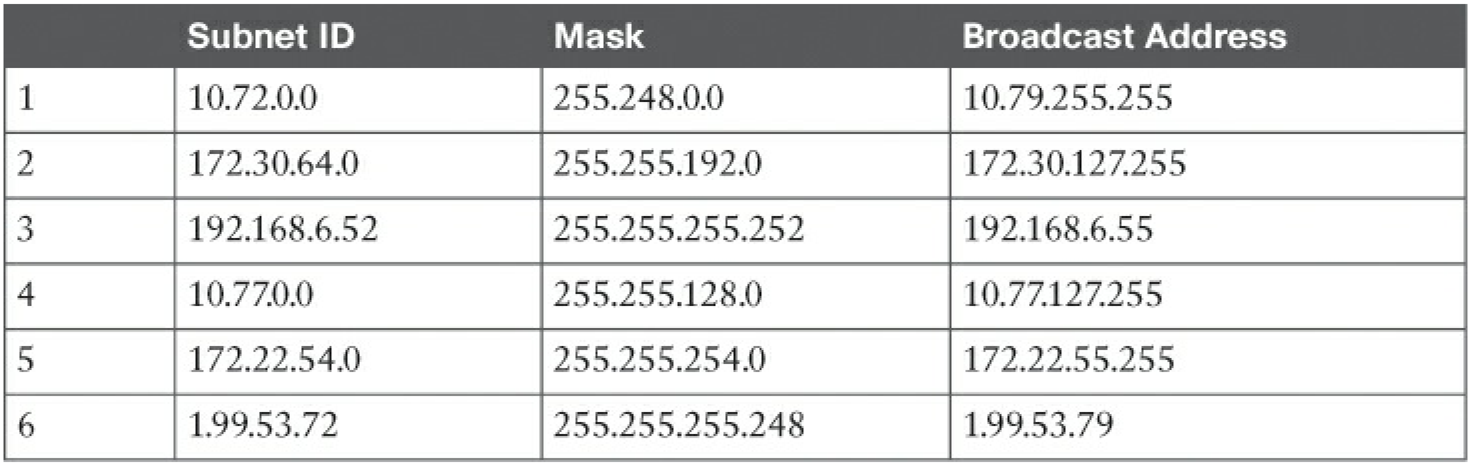
	IP Address	Mask	Subnet ID	Broadcast Address
1	10.77.55.3	255.255.255.0	10.77.55.0	10.77.55.255
2	172.30.99.4	255.255.255.0	172.30.99.0	172.30.99.255
3	192.168.6.54	255.255.255.0	192.168.6.0	192.168.6.255
4	10.77.3.14	255.255.0.0	10.77.0.0	10.77.255.255
5	172.22.55.77	255.255.0.0	172.22.0.0	172.22.255.255
6	1.99.53.76	255.0.0.0	1.0.0.0	1.255.255.255

Table 14-15. Answers to Problems in Table 14-10



	IP Address	Mask	Subnet ID
1	10.77.55.3	255.248.0.0	10.72.0.0
2	172.30.99.4	255.255.192.0	172.30.64.0
3	192.168.6.54	255.255.255.252	192.168.6.52
4	10.77.3.14	255.255.128.0	10.77.0.0
5	172.22.55.77	255.255.254.0	172.22.54.0
6	1.99.53.76	255.255.255.248	1.99.53.72

Table 14-16. Answers to Problems in the Section "Subnet Broadcast Address Practice Problems"



	Subnet ID	Mask	Broadcast Address
1	10.72.0.0	255.248.0.0	10.79.255.255
2	172.30.64.0	255.255.192.0	172.30.127.255
3	192.168.6.52	255.255.255.252	192.168.6.55
4	10.77.0.0	255.255.128.0	10.77.127.255
5	172.22.54.0	255.255.254.0	172.22.55.255
6	1.99.53.72	255.255.255.248	1.99.53.79

The following list explains the answers for Table 14-15:

1. The second octet is the interesting octet, with magic number 256 – 248 = 8. The multiples of 8 include 0, 8, 16, 24, ..., 64, 72, and 80. 72 is closest to the IP address value in that same octet (77) without going over, making the subnet ID 10.72.0.0.
2. The third octet is the interesting octet, with magic number 256 – 192 = 64. The multiples of 64 include 0, 64, 128, and 192. 64 is closest to the IP address value in that same octet (99) without going over, making the subnet ID 172.30.64.0.
3. The fourth octet is the interesting octet, with magic number 256 – 252 = 4. The multiples of 4 include 0, 4, 8, 12, 16, ..., 48, and 52, 56. 52 is the closest to the IP address value in that same octet (54) without going over, making the subnet ID 192.168.6.52.
4. The third octet is the interesting octet, with magic number 256 – 128 = 128. Only two multiples exist that matter: 0 and 128. 0 is the closest to the IP address value in that same octet (3) without going over, making the subnet ID 10.77.0.0.
5. The third octet is the interesting octet, with magic number 256 – 254 = 2. The multiples of 2 include 0, 2, 4, 6, 8, and so on—essentially all even numbers. 54 is closest to the IP address value in that same octet (55) without going over, making the subnet ID 172.22.54.0.
6. The fourth octet is the interesting octet, with magic number 256 – 248 = 8. The multiples of 8 include 0, 8, 16, 24, ...,

64, 72, and 80. 72 is closest to the IP address value in that same octet (76) without going over, making the subnet ID 1.99.53.72.

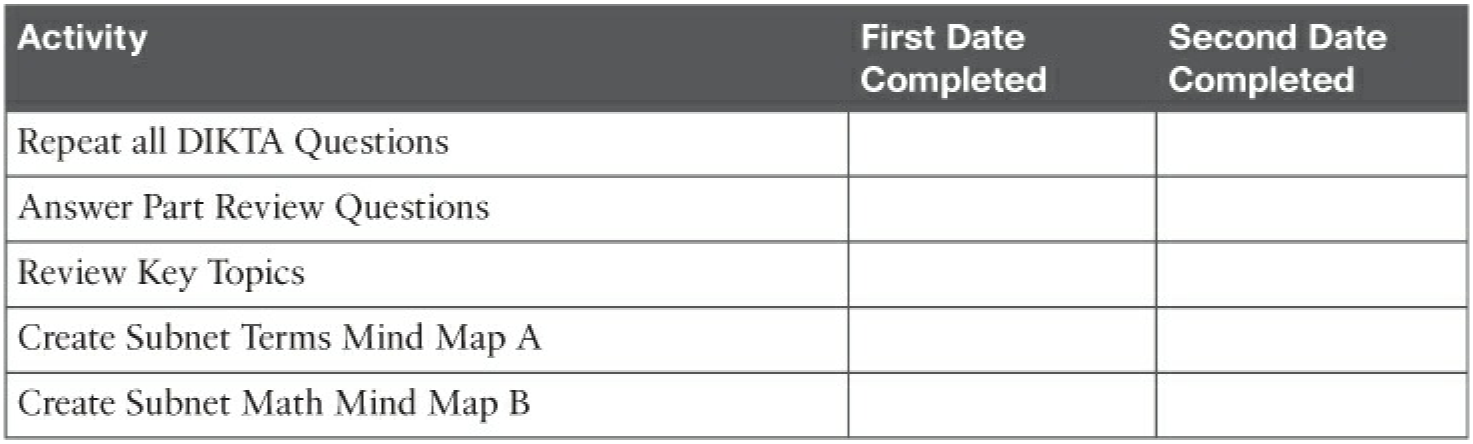
The following list explains the answers for Table 14-16:

1. The second octet is the interesting octet. Completing the three easy octets means that the broadcast address in the interesting octet will be 10.___.255.255. With a magic number 256 – 248 = 8, the second octet will be 72 (from the subnet ID), plus 8, minus 1, or 79.
2. The third octet is the interesting octet. Completing the three easy octets means that the broadcast address in the interesting octet will be 172.30.___.255. With magic number 256 – 192 = 64, the interesting octet will be 64 (from the subnet ID), plus 64 (the magic number), minus 1, for 127.
3. The fourth octet is the interesting octet. Completing the three easy octets means that the broadcast address in the interesting octet will be 192.168.6.___. With magic number 256 – 252 = 4, the interesting octet will be 52 (the subnet ID value), plus 4 (the magic number), minus 1, or 55.
4. The third octet is the interesting octet. Completing the three easy octets means that the broadcast address will be 10.77.___.255. With magic number 256 – 128 = 128, the interesting octet will be 0 (the subnet ID value), plus 128 (the magic number), minus 1, or 127.
5. The third octet is the interesting octet. Completing the three easy octets means that the broadcast address will be 172.22.___.255. With magic number 256 – 254 = 2, the broadcast address in the interesting octet will be 54 (the subnet ID value), plus 2 (the magic number), minus 1, or 55.
6. The fourth octet is the interesting octet. Completing the three easy octets means that the broadcast address will be 1.99.53.___. With magic number 256 – 248 = 8, the broadcast address in the interesting octet will be 72 (the subnet ID value), plus 8 (the magic number), minus 1, or 79.

Part III Review

Keep track of your part review progress with the checklist in Table P3-1. Details on each task follow the table.

Table P3-1. Part III Part Review Checklist



Activity	First Date Completed	Second Date Completed
Repeat all DIKTA Questions		
Answer Part Review Questions		
Review Key Topics		
Create Subnet Terms Mind Map A		
Create Subnet Math Mind Map B		

Repeat All DIKTA Questions

For this task, answer the "Do I Know This Already?" questions again for the chapters in this part of the book, using the PCPT software. Refer to the Introduction to this book, heading "How to View Only DIKTA Questions by Part," for help with how to make the PCPT software show you DIKTA questions for this part only.

Answer Part Review Questions

For this task, answer the Part Review questions for this part of the book, using the PCPT software. Refer to the Introduction to this book, heading "How to View Only Part Review Questions by Part," for help with how to make the PCPT software show you Part Review questions for this part only.

Review Key Topics

Key Topic

Browse back through the chapters, and look for the Key Topic icons. If you do not remember some details, take the time to reread those topics.

Create Terminology Mind Map

The topic of IPv4 addressing and subnetting happens to have many terms that are literal synonyms, many terms with similar meanings, along with terms that describe something about another term. This first Part Review mind map (Part III, Mind Map A) asks you to organize all IP addressing and subnetting terms you remember into four topic areas, but inside each area, subdivide terms as to whether they are either a synonym, a similar term, or a description.

Figure P3-1 shows the beginnings of one branch of the mind map to give you the general idea. For this branch, you would just remember any terms related to "IP address" and place them into one of these three categories. Your map can of course look different. As usual, first do this exercise without the book or your notes. Later, when you do look at the book again, make sure that you have at least included all the key terms from the ends of the chapters.

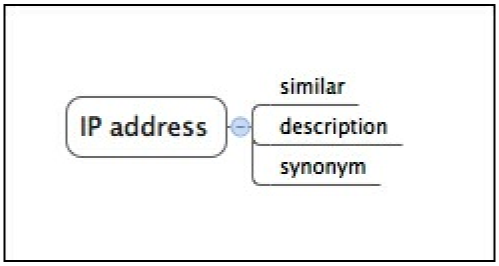


Figure P3-1. Sample Beginning Point for Part III Mind Map A

> **Note**
>
> For more information on mind mapping, refer to the Introduction, in the section "About Mind Maps."

Create Subnet Math Mind Maps

This book part explains several types of subnetting problems that you can analyze and solve. The next mind map exercise helps to review the big ideas of what each type of problem does. This review does not focus on the details of how to find the answer to any one problem, leaving that for all the other practice suggestions included near the end of Chapters 12, 13, and 14. Those chapters discussed four major types of problems that can be solved with some arithmetic:

- **Classful Facts:** Based on an IP address, find many facts about the associated classful IP network.
- **Mask Conversion:** Given a subnet mask, find the equivalent mask in the other two mask formats.
- **Mask Analysis:** Given a subnet mask, address, and an assumption, find the number of hosts per subnet and the number of subnets.
- **Subnet Analysis:** Given a subnet mask and address, find the numbers that define the resident subnet (the subnet ID, subnet broadcast address, and range of usable IP addresses).

Create a mind map with four branches, one for each topic in the list. For each branch, begin with the core concept, and branch into three subtopics:

- **Given:** The information you have and the assumptions you make to start the problem.
- **Process:** The information or terms used during the process. Do not write the specific steps of the process; the goal here is just to make memory connections so that you know it is this process, and not some other process.
- **Result:** The facts you determine by doing the problem.

Figure P3-2 shows an example (incomplete) map for the classful facts problem, just to show the basic idea.

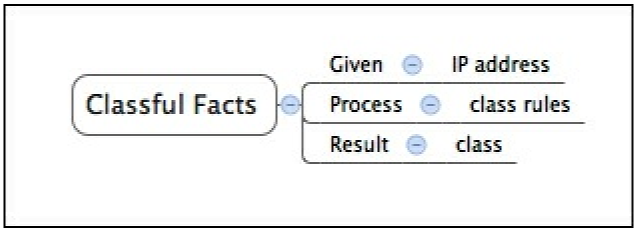
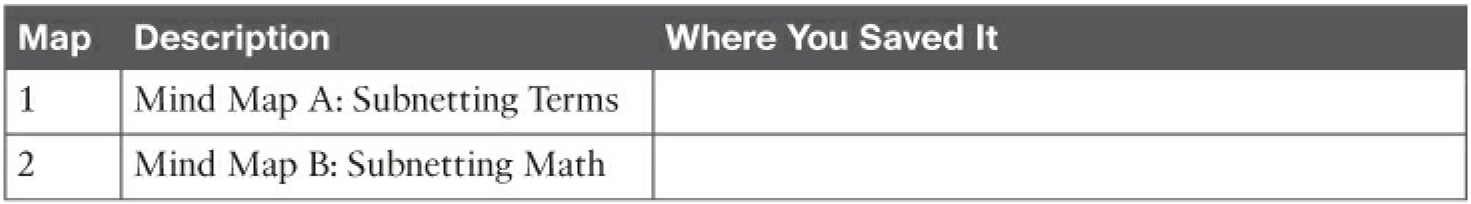


Figure P3-2. Sample Mind Map for Part III Mind Map B

If you do choose to use mind map software, rather than paper, you might want to remember where you stored your mind map files; Table P3-2 lists the mind maps for this part review and a place to record those filenames.

Table P3-2. Configuration Mind Maps for Part III Review



Map	Description	Where You Saved It
1	Mind Map A: Subnetting Terms	
2	Mind Map B: Subnetting Math	

Appendix O, "Mind Map Solutions," lists sample mind map answers, but as usual, your mind maps can and will look different.

Part IV: Implementing IP Version 4

Implementing IPv4 in a network begins with the configuration of IPv4 addresses on hosts and routers, along with IPv4 routing protocols that learn routes to the subnets in that network. Part IV walks you through these details. Chapter 15 focuses on Cisco routers as an end to themselves, with Chapter 16 focusing on router IPv4 address and static IPv4 route configuration. With those details configured, Chapter 17 focuses on adding OSPF configuration to the routers so that the routers learn routes. The final chapter in this part (18) then discusses implementing IPv4 on hosts and describes how hosts think about IPv4, with some discussion of basic testing tools to test all the features discussed in this part.

Chapter 15: Operating Cisco Routers

Chapter 16: Configuring IPv4 Addresses and Routes

Chapter 17: Learning IPv4 Routes with OSPFv2

Chapter 18: Configuring and Verifying Host Connectivity

Part IV Review

Chapter 15. Operating Cisco Routers

This chapter covers the following exam topics:

Operation of IP Data Networks

Recognize the purpose and functions of various network devices such as Routers, Switches, Bridges, and Hubs.

Select the components required to meet a given network specification.

Identify the appropriate media, cables, ports, and connectors to connect Cisco network devices to other network devices and hosts in a LAN

IP Routing Technologies

Configure and verify utilizing the CLI to set basic Router configuration

Network Device Security

Configure and verify network device security features such as

- Device password security
- Enable secret vs enable

Troubleshooting

Troubleshoot and correct common problems associated with IP addressing and host configurations.

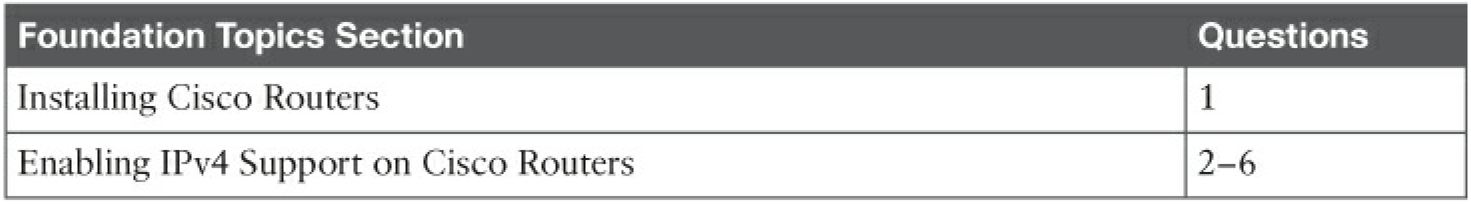
This chapter focuses on how to install an enterprise-class Cisco router, with just enough configuration to get the router working. You might recall, when you buy a Cisco LAN switch, you can just plug in all the Ethernet cables, power on the switch, and by default, the switch works. However, the Cisco routers used by companies require at least some configuration before the router will start routing IPv4 packets. In particular, the router needs to be told what interfaces to use and what IP address to use on each of those interfaces.

This chapter breaks the topics into two major headings. The first discusses the physical installation of an enterprise-class Cisco router. The second section looks at the command-line interface (CLI) on a Cisco router, which has the same look and feel as the Cisco switch CLI. This section first lists the similarities between a switch and router CLI, and then introduces the configuration required to make the router start forwarding IP packets on its interfaces.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 15-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Installing Cisco Routers	1
Enabling IPv4 Support on Cisco Routers	2–6

1. Which of the following installation steps are typically required on a Cisco router, but not typically required on a Cisco switch? (Choose two answers.)
   - **a.** Connect Ethernet cables
   - **b.** Connect serial cables
   - **c.** Connect to the console port
   - **d.** Connect the power cable
   - **e.** Turn the on/off switch to "on"
2. Which of the following commands might you see associated with the router CLI, but not with the switch CLI?
   - **a.** The **clock rate** command
   - **b.** The **ip address** *address mask* command
   - **c.** The **ip address dhcp** command
   - **d.** The **interface vlan 1** command
3. You just bought two Cisco routers for use in a lab, connecting each router to a different LAN switch with their Fa0/0 interfaces. You also connected the two routers' serial interfaces using a back-to-back cable. Which of the following steps are not required to be able to forward IPv4 packets on both routers' interfaces? (Choose two answers.)
   - **a.** Configuring an IP address on each router's Fast Ethernet and serial interfaces
   - **b.** Configuring the **bandwidth** command on one router's serial interface
   - **c.** Configuring the **clock rate** command on one router's serial interface

d. Setting the interface **description** on both the Fast Ethernet and serial interface of each router

4. The output of the **show ip interface brief** command on R1 lists interface status codes of "down" and "down" for interface Serial 0/0. Which of the following could be true?

a. The **shutdown** command is currently configured for that interface.

b. R1's serial interface has been configured to use Frame Relay, but the router on the other end of the serial link has been configured to use PPP.

c. R1's serial interface does not have a serial cable installed.

d. Both routers have been cabled to a working serial link (CSU/DSUs included), but only one router has been configured with an IP address.

5. Which of the following commands do not list the IP address and mask of at least one interface? (Choose two answers.)

a. show running-config

b. show protocols *type number*

c. show ip interface brief

d. show interfaces

e. show version

6. Which of the following is different on the Cisco switch CLI as compared with the Cisco router CLI?

a. The commands used to configure simple password checking for the console

b. The number of IP addresses configured

c. The configuration of the device's host name

d. The configuration of an interface description

Answers to the "Do I Know This Already?" quiz:

1 B and E **2** A **3** B and D **4** C **5** C and E **6** B

Foundation Topics

Installing Cisco Routers

Routers collectively provide the main feature of the network layer—the capability to forward packets end to end through a network. As introduced in Chapter 4, "Fundamentals of IPv4 Addressing and Routing," routers forward packets by connecting to various physical network links, like Ethernet, serial links, and Frame Relay, and then using Layer 3 routing logic to choose where to forward each packet. As a reminder, Chapter 2, "Fundamentals of Ethernet LANs," covered the details of making those physical connections to Ethernet networks, while Chapter 3, "Fundamentals of WANs," covered the basics of cabling with WAN links.

This section examines some of the details of router installation and cabling, first from the enterprise perspective and then from the perspective of connecting a typical small office/home office (SOHO) to an ISP using high-speed Internet.

Installing Enterprise Routers

A typical enterprise network has a few centralized sites as well as lots of smaller remote sites. To support devices at each site (the computers, IP phones, printers, and other devices), the network includes at least one LAN switch at each site. Additionally, each site has a router, which connects to the LAN switch and to some WAN link. The WAN link provides connectivity from each remote site, back to the central site, and to other sites through the connection to the central site.

Figures 15-1 and 15-2 show contrasting ways to draw parts of an enterprise network. Both show a typical branch office on the left, with a router and some end-user PCs. The central site, on the right, has basically the same components, plus some servers. The sites connect using a point-to-point serial link connecting the two routers. The first figure omits many of the cabling details, making the figure more useful when you want to discuss general Layer 3 concepts; the second figure shows the cabling details.

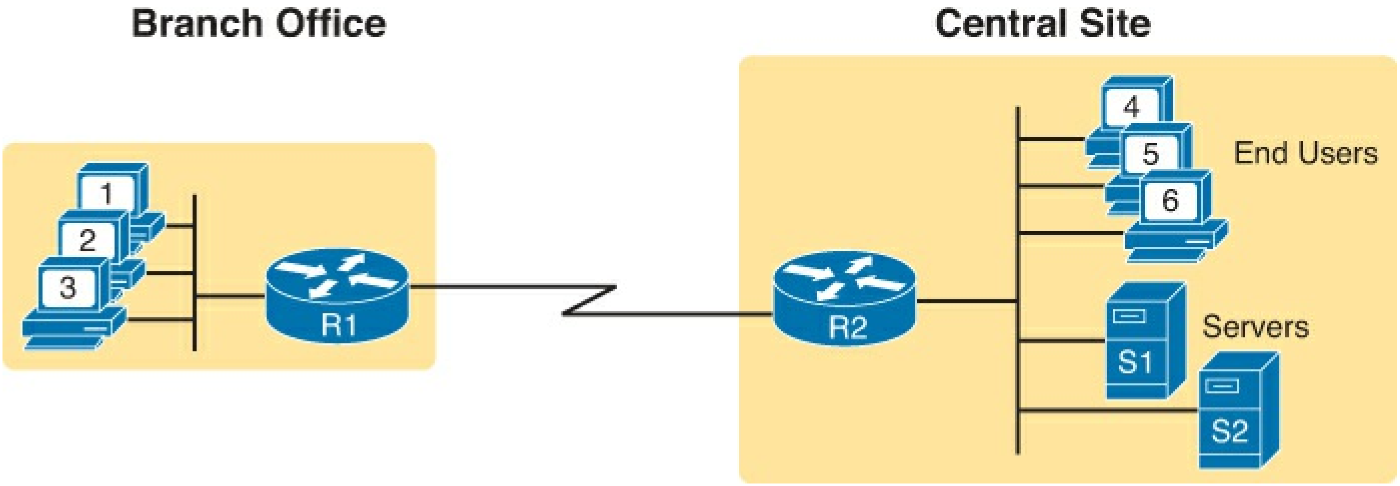


Figure 15-1. Generic Enterprise Network Diagram

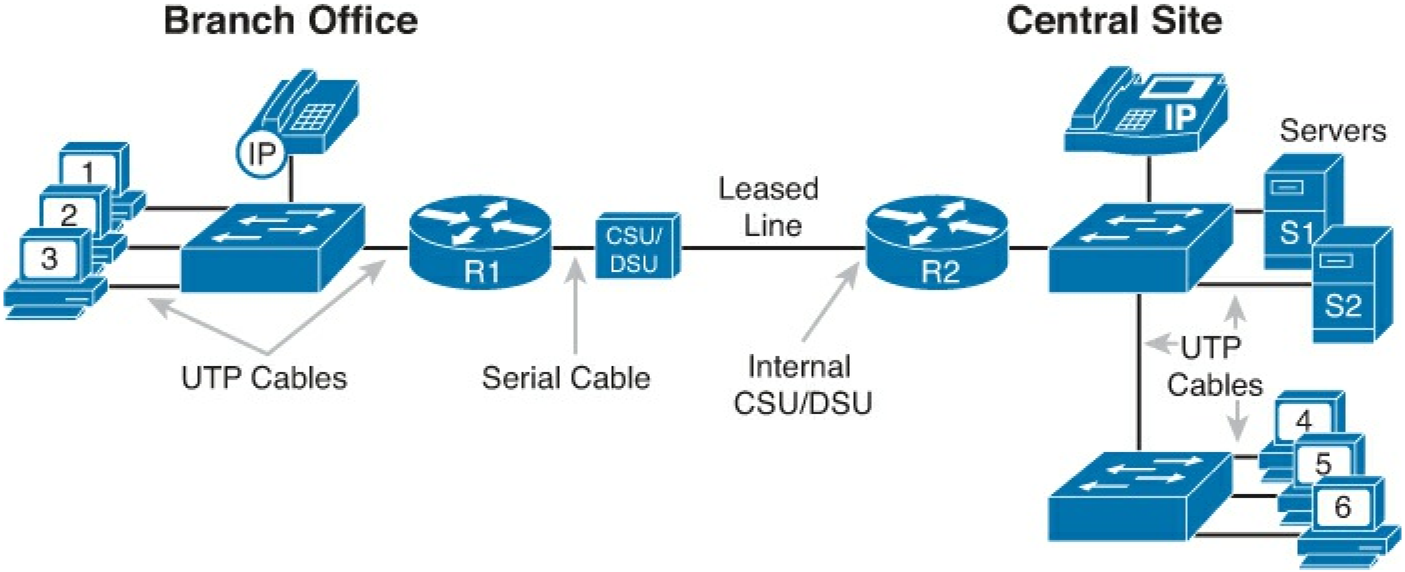


Figure 15-2. More Detailed Cabling Diagram for the Same Enterprise Network

The Ethernet cables in Figure 15-2 should be familiar. In particular, routers use the same Ethernet cabling pinouts as PCs, so each router uses a UTP cable with a straight-through pinout.

Next, consider the hardware on the ends of the serial link, in particular where the channel service unit/data service unit (CSU/DSU) hardware resides on each end of the serial link. It sits either outside the router as a separate device (as shown on the left) or integrated into the router's serial interface hardware (as shown on the right). Most new installations today include the CSU/DSU in the router's serial interface.

Finally, the serial link requires some cabling inside the same wiring closet or other space between where the telco serial line terminates and where the router sits on a shelf or in a rack. The WAN cable installed by the telco typically has an RJ-48 connector, which is the same size and shape as an RJ-45 connector. The telco cable with the RJ-48 connector inserts into the CSU/DSU. In the example of Figure 15-2, at the central site, the telco cable connects directly into the router's serial interface. At the branch office router, the cable connects to the external CSU/DSU, which then connects to the router serial interface using some other serial cable. (As a reminder, Chapter 3's section "Leased Line Cabling" introduced the basics of this cabling.)

Cisco Integrated Services Routers

Product vendors, including Cisco, typically provide several different types of router hardware, including some routers that just do routing, with other routers that serve other functions in addition to routing. A typical enterprise branch office needs a router for WAN/LAN connectivity, and a LAN switch to provide a high-performance local network and connectivity into the router and WAN. Many branches also need Voice over IP (VoIP) services and several security services as well. (One popular security service, Virtual Private Networking [VPN], is covered in Chapter 5, "Fundamentals of TCP/IP Transport and Applications.") Rather than require multiple separate devices at one site, as shown in Figure 15-2, Cisco offers single devices that act as both router and switch, and provide other functions as well.

Following that concept further, Cisco offers several router model series in which the routers support many other functions. In fact, Cisco has several router product series called Integrated Services Routers (ISR), with the name emphasizing the fact that many functions are integrated into a single device. However, for the sake of learning and understanding the different functions, the CCENT and CCNA exams focus on using a separate switch and separate router, which provides a much cleaner path for learning the basics.

Figure 15-3 shows a couple of pictures of the Cisco 2901 ISR, with some of the more important features highlighted. The top part of the figure shows a full view of the back of the router. This model comes with two built-in Gigabit Ethernet interfaces and four modular slots that allow you to add small cards called WAN interface cards (WIC) that add other interfaces. The bottom of the figure shows one example WIC, which would take one of the four slots after it is installed. The router has other items as well, including both an RJ-45 and USB console port.

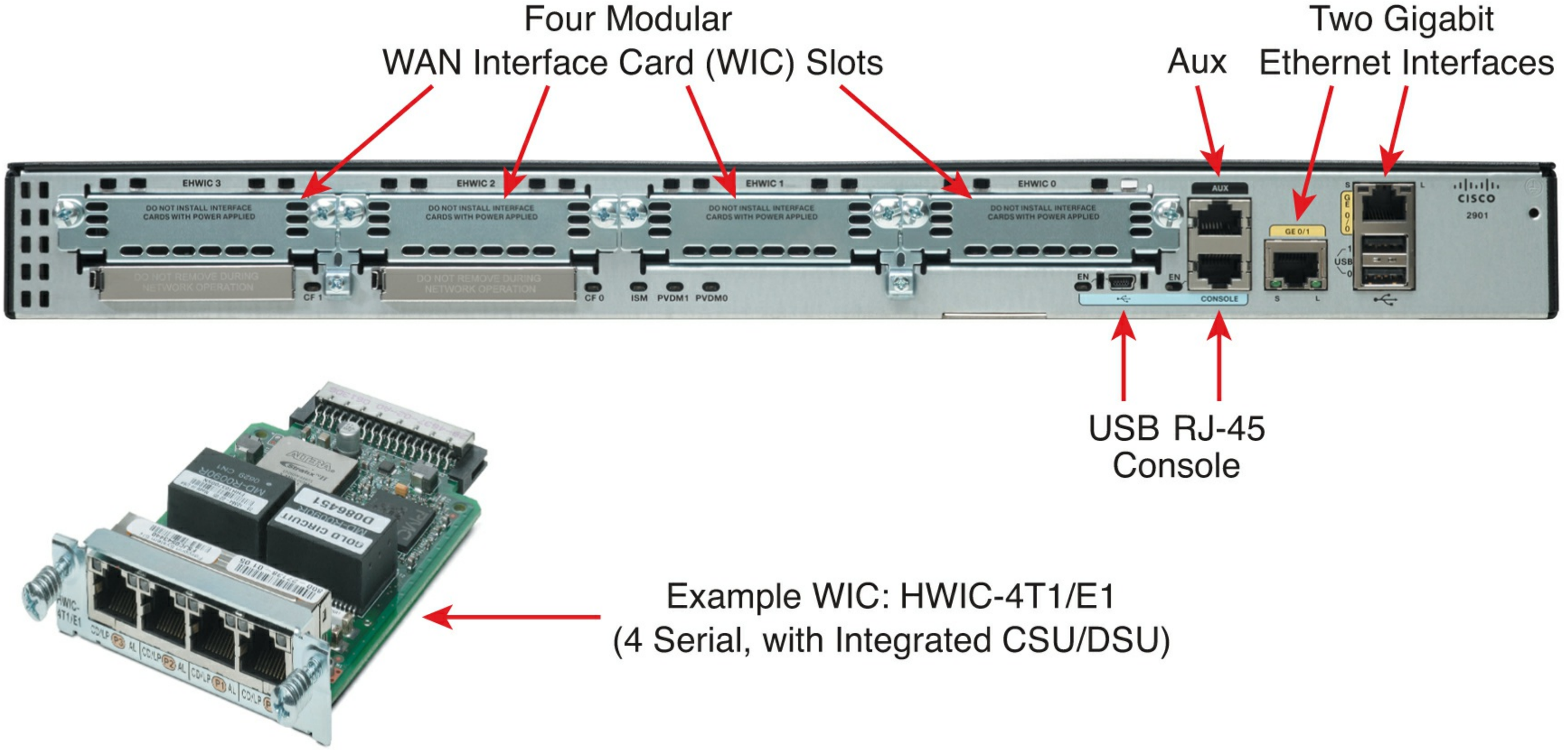


Figure 15-3. Photos of a Model 2901 Cisco Integrated Services Router (ISR)

Physical Installation

Armed with the cabling details in figures like Figure 15-2, and the router hardware details in figures like Figure 15-3, you can physically install a router. To install a router, follow these steps:

Key Topic

Step 1. Connect any LAN cables to the LAN ports.

Step 2. If using an external CSU/DSU, connect the router's serial interface to the CSU/DSU and the CSU/DSU to the line from the telco.

Step 3. If using an internal CSU/DSU, connect the router's serial interface to the line from the telco.

Step 4. Connect the router's console port to a PC (using a rollover cable), as needed, to configure the router.

Step 5. Connect a power cable from a power outlet to the power port on the router.

Step 6. Power on the router.

Note that the steps for router installation match those for a switch, except that Cisco enterprise routers typically have an on/off switch, while switches do not.

Installing Internet Access Routers

Routers play a key role in SOHO networks, connecting the LAN-attached end-user devices to a high-speed Internet access service. After they are connected to the Internet, SOHO users can send packets to and from their enterprise network at their company or school.

Vendors like Cisco offer router products that primarily act as routers and other products that combine routing functions with many other functions. However, to make learning each function more obvious, this section first shows each function as a separate device and later shows a more typical example with many functions combined into one integrated networking device.

A SOHO Installation with a Separate Switch, Router, and Cable Modem

Figure 15-4 shows an example of the devices and cables used in a SOHO network to connect to the Internet using cable TV (CATV) as the high-speed Internet service. For now, keep in mind that the figure shows one alternative for the devices and cables, whereas many variations are possible.

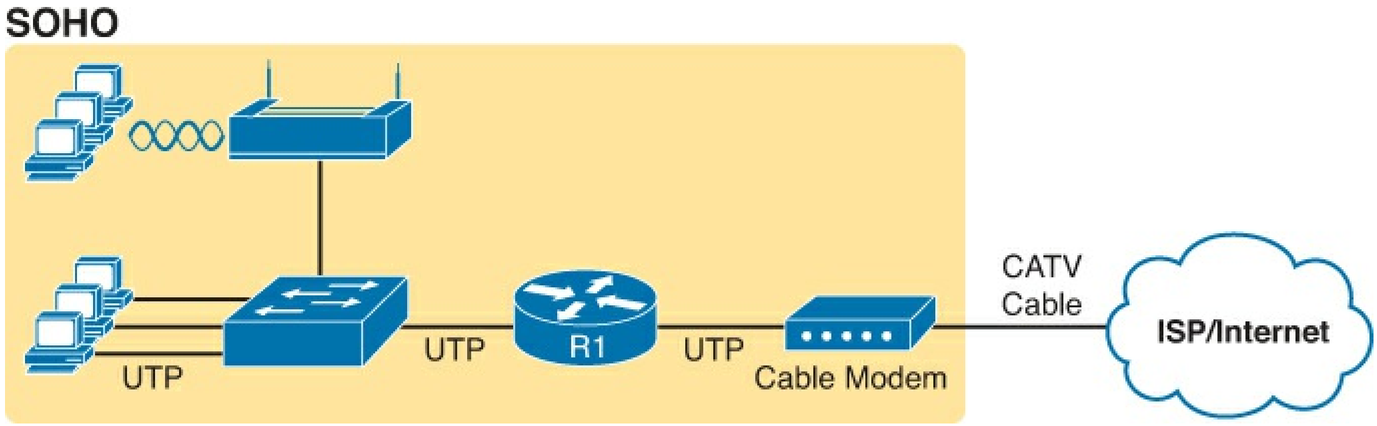


Figure 15-4. Devices in a SOHO Network with High-Speed CATV Internet

This figure has many similarities to Figure 15-2, which shows a typical enterprise branch office. Some end-user PCs still connect to a switch, and the switch still connects to a router's Ethernet interface. Other end-user devices use a wireless LAN, with a wireless access point, that also connects to the Ethernet LAN. For both the wired and wireless devices, the router still provides routing services, forwarding IP packets.

The main differences between the SOHO connection in Figure 15-4 and the enterprise branch in Figure 15-2 relate to the connection into the Internet. An Internet connection that uses CATV or digital subscriber line (DSL) needs a device that converts between the Layer 1 and 2 standards used on the CATV cable or DSL line and the Ethernet used by the router. These devices, commonly called *cable modems* and *DSL modems*, respectively, convert electrical signals between an Ethernet cable and either CATV or DSL.

In fact, while the details differ greatly, the purpose of the cable modem and DSL modem is similar to a CSU/DSU on a serial link. A CSU/DSU converts between the Layer 1 standards used on a telco's WAN circuit and a serial cable's Layer 1 standards. Similarly, a cable modem converts between CATV signals and a Layer 1 (and Layer 2) standard usable by a router—namely, Ethernet. Similarly, DSL modems convert between the DSL signals over a home telephone line and Ethernet.

To physically install a SOHO network with the devices shown in Figure 15-4, you basically need the correct UTP cables for the Ethernet connections, and either the CATV cable (for cable Internet services) or a phone line (for DSL services). Note that the router used in Figure 15-4 simply needs to have two Ethernet interfaces—one to connect to the LAN switch and one to connect to the cable modem. Thinking specifically just about the router installation, you would need to use the following steps to install this SOHO router:

Step 1. Connect a UTP straight-through cable from the router to the switch.

Step 2. Connect a UTP straight-through cable from the router to the cable modem.

Step 3. Connect the router's console port to a PC (using a rollover cable), as needed, to configure the router.

Step 4. Connect a power cable from a power outlet to the power port on the router.

Step 5. Power on the router.

A SOHO Installation with an Integrated Switch, Router, and DSL Modem

Today, most new SOHO installations use an integrated device rather than the separate devices shown in Figure 15-4. In fact, you can buy a single SOHO device today that includes all of these functions:

- Router
- Switch
- Cable or DSL modem
- Wireless access point
- Hardware-enabled encryption

A newly installed high-speed SOHO Internet connection today probably looks more like Figure 15-5, with an integrated device. In fact, when you go to a typical office supply store today and look at consumer devices called a "router," it is likely one of these integrated devices that does many functions.

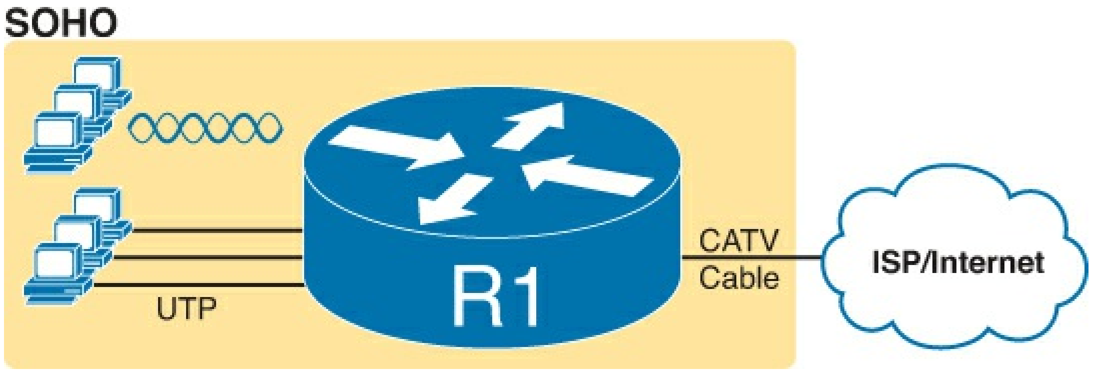


Figure 15-5. SOHO Network, Using Cable Internet and an Integrated Device

Enabling IPv4 Support on Cisco Routers

Routers support a relatively large number of features, with a large number of configuration and EXEC commands to support those features. This section introduces the most commonly used commands: a variety of administrative commands, plus the commands used to enable IPv4 processing on LAN and WAN interfaces.

> **Note**
>
> For perspective, the Cisco router documentation includes a command reference, with an index to every single router command. A quick informal count of a recent IOS version listed around 5000 CLI commands.

Thankfully, learning router administrative commands requires only a little work, because many Cisco router and Cisco switch administrative features use the exact same commands. For example, the console, vty, and enable passwords all work the same. This section begins with a review of the CLI features you have already learned from Part II of this book and reviews which ones do indeed work the same way on Cisco routers and switches.

The rest of this section focuses on the basic commands related to router interfaces. In particular, this section explains the configuration required to enable IPv4 processing on a router interface.

Comparisons Between the Switch CLI and Router CLI

The following list details the many items covered in Chapter 8, "Configuring Ethernet Switching," for which the router CLI behaves the same. If these details are not fresh in your memory, it might be worthwhile to spend a few minutes briefly reviewing Chapter 8.

The configuration commands used for the following features are the same on both routers and switches:

- User and Enable (privileged) mode
- Entering and exiting configuration mode, using the **configure terminal**, **end**, and **exit** commands and the Ctrl+Z key sequence
- Configuration of console, Telnet, and enable secret passwords
- Configuration of SSH encryption keys and username/password login credentials
- Configuration of the hostname and interface description
- Configuration of Ethernet interfaces that can negotiate speed, using the **speed** and **duplex** commands
- Configuring an interface to be administratively disabled (**shutdown**) and administratively enabled (**no shutdown**)
- Navigation through different configuration mode contexts using commands like **line console 0** and **interface**
- CLI help, command editing, and command recall features
- The use of the **debug** command's many options to create log messages about certain events, so that any user can monitor those messages using the **terminal monitor** EXEC command
- Setup mode, used to guide the user through a set of questions to create a simple initial configuration
- The meaning and use of the startup config (in NVRAM), running config (in RAM), and external servers (like TFTP), along with how to use the **copy** command to copy the configuration files and IOS images

At first glance, this list seems to cover most everything covered in Chapter 8—and it does cover most of the details. However, a couple of topics covered in Chapter 8 do work differently with the router CLI as compared to the switch CLI, namely:

- The configuration of IP addresses differs in some ways.
- Routers have an auxiliary (Aux) port, intended to be connected to an external modem and phone line to allow remote users to dial in to the router, and access the CLI, by making a phone call.

Beyond these two items from Chapter 8, the router CLI does differ from a switch CLI just because switches and routers do different things. For example, Cisco Layer 2 switches support the **show mac address-table** command, but these Layer 2–only devices do not support the **show ip route** command, which lists IP routes. Some Cisco routers can do IP routing but not Layer 2 switching, so they support the **show ip route** command but not the **show mac address-table** command.

Router Interfaces

One minor difference between Cisco switches and routers is that routers support a much wider variety of interfaces. Today, LAN switches support Ethernet LAN interfaces of various speeds. Routers support a variety of other types of interfaces, including serial interfaces, cable TV, DSL, and others not mentioned in this book.

Most Cisco routers have at least one Ethernet interface of some type. Many of those Ethernet interfaces support multiple speeds and use autonegotiation, so for consistency, the router IOS refers to these interfaces based on the fastest speed. For example, a 10-Mbps-only Ethernet interface would be configured with the **interface ethernet** *number* configuration command, a 10/100 interface with the **interface fastethernet** *number* command, and a 10/100/1000 interface with the **interface gigabitethernet** *number* command.

Serial interfaces make up the second most common type of router interface shown in this book. As you might recall from Chapter 3, Cisco routers use serial interfaces to connect to a serial link. Each point-to-point serial link can then use High-Level Data Link Control (HDLC, the default) or Point-to-Point Protocol (PPP).

Routers refer to interfaces in many commands, first by the type of interface (Ethernet, Fast Ethernet, Serial, and so on) and then with a unique number of that router. On routers, the interface numbers might be a single number, two numbers separated by a slash, or three numbers separated by slashes. For example, all three of the following configuration commands are correct on at least one model of Cisco router:

```
interface ethernet 0
interface fastEthernet 0/1
interface gigabitethernet 0/0
interface serial 1/0/1
```

Two of the most common commands to display the interfaces, and their status, are the **show ip interface brief** and **show interfaces** commands. The first of these commands displays a list with one line per interface, with some basic information, including the interface IP address and interface status. The second command lists the interfaces, but with a large amount of information per interface. Example 15-1 shows a sample of each command.

Example 15-1. Listing the Interfaces in a Router

Click here to view code image

```
R1# show ip interface brief
Interface IP-Address OK? Method Status Protocol
Embedded-Service-Engine0/0 unassigned YES NVRAM administratively down down
GigabitEthernet0/0 172.16.1.1 YES NVRAM down down
GigabitEthernet0/1 unassigned YES manual administratively down down
Serial0/0/0 172.16.4.1 YES NVRAM up up
Serial0/0/1 172.16.5.1 YES NVRAM up up
Serial0/1/0 unassigned YES NVRAM up up
Serial0/1/1 unassigned YES NVRAM administratively down down

R1# show interfaces serial 0/0/0
Serial0/0/0 is up, line protocol is up
Hardware is WIC MBRD Serial
Description: Link in lab to R2's S0/0/1
Internet address is 172.16.4.1/24
MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
reliability 255/255, txload 1/255, rxload 1/255
Encapsulation HDLC, loopback not set
Keepalive set (10 sec)
Last input 00:00:03, output 00:00:06, output hang never
Last clearing of "show interface" counters never
Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
Queueing strategy: fifo
Output queue: 0/40 (size/max)
5 minute input rate 0 bits/sec, 0 packets/sec
5 minute output rate 0 bits/sec, 0 packets/sec
42 packets input, 3584 bytes, 0 no buffer
Received 42 broadcasts (0 IP multicasts)
0 runts, 0 giants, 0 throttles
0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored, 0 abort
41 packets output, 3481 bytes, 0 underruns
0 output errors, 0 collisions, 4 interface resets
3 unknown protocol drops
0 output buffer failures, 0 output buffers swapped out
0 carrier transitions
DCD=up DSR=up DTR=up RTS=up CTS=up
```

Note

Commands that refer to router interfaces can be significantly shortened by truncating the words. For

> example, **sh int fa0/0** can be used instead of **show interfaces fastethernet 0/0**. In fact, many network engineers, when looking over someone's shoulder, would say something like "just do a show int F-A-oh-oh command" in this case, rather than speaking the long version of the command.

Also, note that **show interfaces** command lists a text interface description on about the 3rd line, if configured. In this case, interface S0/0/0 had been previously configured with the **description Link in lab to R2's S0/0/1** command in interface configuration mode for interface S0/0/0. The **description** interface subcommand provides an easy way to keep small notes about what router interfaces connect to which neighboring devices, with the **show interfaces** command listing that information.

Interface Status Codes

Each interface has two *interface status codes*. To be usable, the two interface status codes must be in an "up" state. The first status code refers essentially to whether Layer 1 is working, and the second status code mainly (but not always) refers to whether the data link layer protocol is working. Table 15-2 summarizes these two status codes.

Key Topic

Table 15-2. Interface Status Codes and Their Meanings

Name	Location	General Meaning
Line status	First status code	Refers to the Layer 1 status—for example, is the cable installed, is it the right/wrong cable, is the device on the other end powered on?
Protocol status	Second status code	Refers generally to the Layer 2 status. It is always down if the line status is down. If the line status is up, a protocol status of down is usually caused by a mismatched data link layer configuration.

Several combinations of interface status codes exist, as summarized in Table 15-3. The table lists the status codes in order, from being disabled on purpose by the configuration to a fully working state.

Key Topic

Table 15-3. Typical Combinations of Interface Status Codes

Line Status	Protocol Status	Typical Reasons
Administratively down	Down	The interface has a **shutdown** command configured on it.
Down	Down	The interface is not **shutdown**, but the physical layer has a problem. For example, no cable has been attached to the interface, or with Ethernet, the switch interface on the other end of the cable is shut down or the switch is powered off.
Up	Down	Almost always refers to data link layer problems, most often configuration problems. For example, serial links have this combination when one router was configured to use PPP and the other defaults to use HDLC.
Up	Up	Layer 1 and Layer 2 of this interface are functioning.

For some examples, look back at Example 15-1's **show ip interface brief** command, to the three interfaces in the following list. The interfaces in this list each have a different combination of interface status codes; the list details the specific reasons for this status code in the lab used to create this example for the book.

G0/0: The interface is down/down, in this case because no cable was connected to the interface.

G0/1: The interface is administratively down/down, because the configuration includes the **shutdown** command under the G0/1 interface.

S0/0/0: The interface is up/up because a serial cable is installed, connected to another router in a lab, and is working.

Router Interface IP Addresses

Cisco enterprise routers require at least some configuration beyond the default configuration before they will do their primary job: routing IP packets. The following facts tell us that to make a router ready to route IPv4 packets on an interface, you need to enable the interface and assign it an IPv4 address:

- Most Cisco router interfaces default to a disabled (**shutdown**) state and should be enabled with the **no shutdown** interface subcommand.
- Cisco routers do not route IP packets in or out an interface until an IP address and mask have been configured; by default, no interfaces have an IP address and mask.
- Cisco routers attempt to route IP packets for any interfaces that are in an up/up state and that have an IP address/mask assigned. (Routers enable IPv4 routing by default due to a default **ip routing** global configuration command.)

To configure the address and mask, simply use the **ip address** *address mask* interface subcommand. Figure 15-6 shows a simple IPv4 network, the same network used in several of the subnetting examples in Part III of this book. The figure shows the IPv4 addresses on Router R1, with Example 15-2 showing the matching configuration.

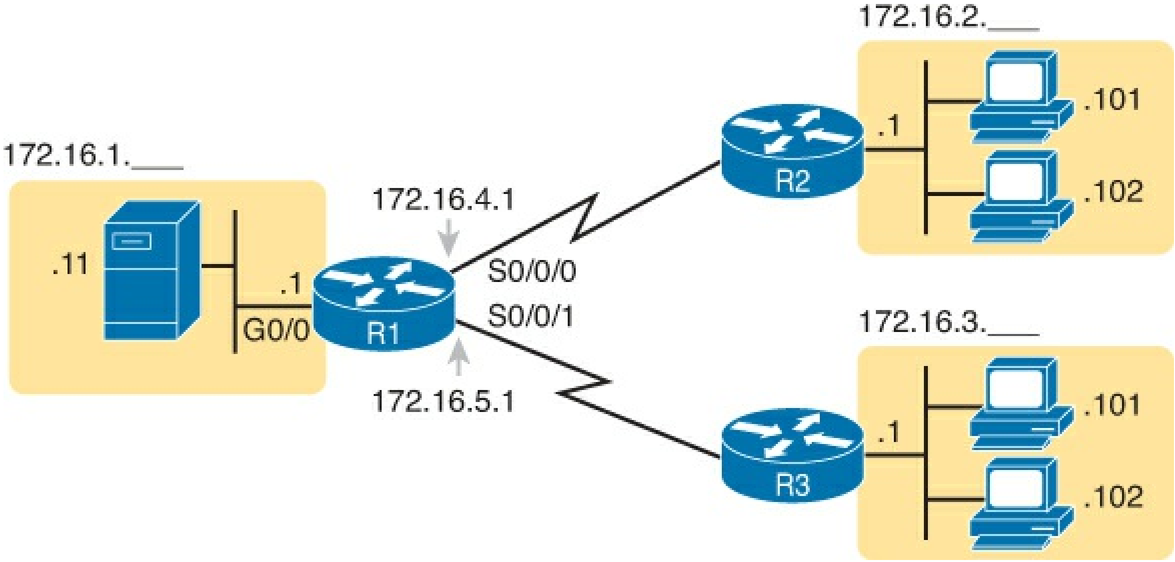


Figure 15-6. IPv4 Addresses Used in Example 15-2

Example 15-2. Configuring IP Addresses on Cisco Routers

Click here to view code image

```
R1# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R1config)# interface G0/0
R1(config-if)# ip address 172.16.1.1 255.255.255.0
R1(config-if)# no shutdown
R1(config-if)# interface S0/0/0
R1(config-if)# ip address 172.16.4.1 255.255.255.0
R1(config-if)# no shutdown
R1(config-if)# interface S0/0/1
R1(config-if)# ip address 172.16.5.1 255.255.255.0
R1(config-if)# no shutdown
R1(config-if)# ^Z
R1#
```

Example 15-3 shows the output of the **show protocols** command. This command confirms the state of each of the three R1 interfaces in Figure 15-6 and the IP address and mask configured on those same interfaces.

Example 15-3. Verifying IP Addresses on Cisco Routers

Click here to view code image

```
R1# show protocols
Global values:
Internet Protocol routing is enabled
Embedded-Service-Engine0/0 is administratively down, line protocol is down
GigabitEthernet0/0 is up, line protocol is up
Internet address is 172.16.1.1/24
GigabitEthernet0/1 is administratively down, line protocol is down
Serial0/0/0 is up, line protocol is up
Internet address is 172.16.4.1/24
Serial0/0/1 is up, line protocol is up
Internet address is 172.16.5.1/24
Serial0/1/0 is administratively down, line protocol is down
Serial0/1/1 is administratively down, line protocol is down
```

One of the first actions to take when verifying whether a router is working is to find the interfaces, check the interface status, and check to see whether the correct IP addresses and masks are used. Examples 15-1 and 15-3 showed samples of the key **show** commands, while Table 15-4 summarizes those commands and the types of information they display.

Table 15-4. Key Commands to List Router Interface Status

Command	Lines of Output per Interface	IP Configuration Listed	Interface Status Listed?
show ip interface brief	1	Address	Yes
show protocols [*type number*]	1 or 2	Address/mask	Yes
show interfaces [*type number*]	Many	Address/mask	Yes

Bandwidth and Clock Rate on Serial Interfaces

Cisco happens to leave most of the details about WAN technologies out of CCENT, with the ICND2 exam and CCNA R/S discussing more details. However, if you decide to build your own study lab with real gear, you need to know just a little more information about serial links. This last topic in the chapter discusses those details.

As mentioned back in Chapter 3, WAN links can run at a wide variety of speeds. To deal with the wide range of speeds, routers physically slave themselves to the speed as dictated by the CSU/DSU through a process called *clocking*. As a result, routers can use serial links without the need for additional configuration or autonegotiation to sense the serial link's speed. The CSU/DSU knows the speed, the CSU/DSU sends clock pulses over the cable to the router, and the router reacts to the clocking signal.

To build a serial link in a home lab, the routers can use serial interface cards that normally use an external CSU/DSU, and make a serial link, without requiring the expense of two CSU/DSUs. Chapter 3's Figure 3-5 introduced this concept, and it is repeated here as Figure 15-7. To make it work, the link uses two serial cables—one a DTE cable and the other a DCE cable—which swap the transmit and receive pair on the cables.

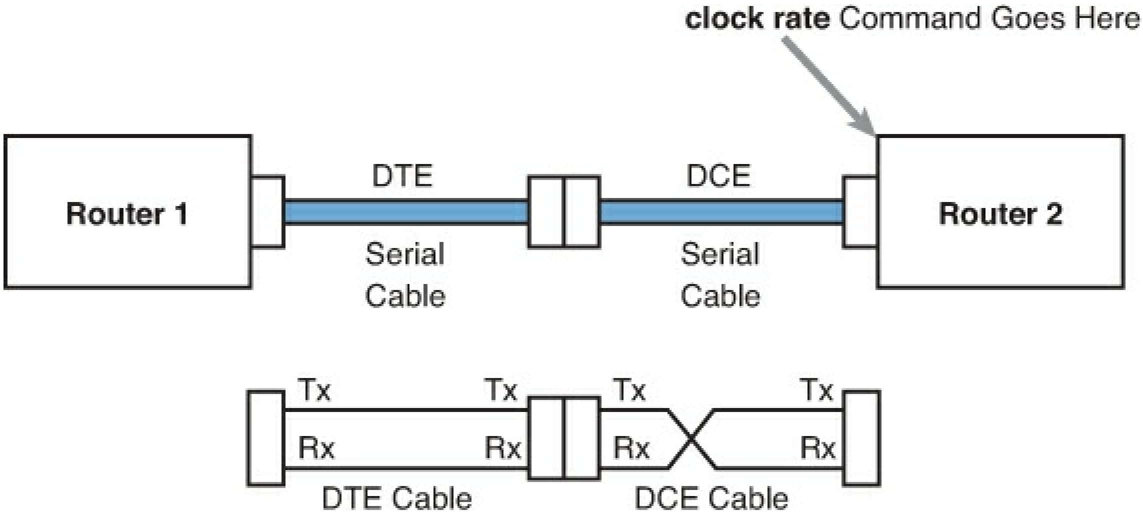


Figure 15-7. Serial Link in Lab

Using the correct cabling works, as long as you add one command: the **clock rate** interface subcommand. This command tells that router the speed at which to transmit bits on a serial link like the one shown in Figure 15-7. The **clock rate** command is not needed on real serial links, because the CSU/DSU provides the clocking. Without any real CSU/DSUs on the link, the router with the DCE cable must supply that clocking function, and the **clock rate** command tells the router to provide it.

> **Note**
>
> Some versions of IOS will automatically implement a default **clock rate 20000000** command on serial interfaces that have a DCE cable connected to them. While helpful, this speed might be too high for some types of back-to-back serial cables, so consider using a lower speed in lab.

Example 15-4 shows the configuration of the **clock rate** command using the same Router R1 used in the earlier Example 15-2. The end of the example verifies that this router can use the **clock rate** command with the **show controllers** command. This command confirms that R1 has a V.35 DCE cable connected.

> **Note**
>
> Example 15-4 omits some of the output of the **show running-config** command, specifically the parts that do not matter to the information covered here.

Example 15-4. Router R1 Configuration with the clock rate **Command**

Click here to view code image

```
R1# show running-config
! lines omitted for brevity
interface Serial0/0/0
ip address 172.16.4.1 255.255.255.0
clock rate 20000000
!
interface Serial0/0/1
ip address 172.16.5.1 255.255.255.0
clock rate 128000

! lines omitted for brevity

R1# show controllers serial 0/0/1
Interface Serial0
Hardware is PowerQUICC MPC860
DCE V.35, clock rate 128000
idb at 0x8169BB20, driver data structure at 0x816A35E4
! Lines omitted for brevity
```

> **Note**
>
> The **clock rate** command does not allow just any speed to be configured. However, the list of speeds does vary from router to router.

Router Auxiliary (Aux) Port

While both routers and switches have a console port to allow administrative access, routers have an extra physical port called an auxiliary (Aux) port. The Aux port typically serves as a means to make a phone call to connect into the router to issue commands from the CLI.

The Aux port works like the console line, except that the Aux port is typically connected through a cable to an external analog modem, which in turn connects to a phone line. Then, the engineer uses a PC, terminal emulator, and modem to call the remote router. After being connected, the engineer can use the terminal emulator to access the router CLI, starting in user mode as usual.

Aux ports can be configured beginning with the **line aux 0** command to reach aux line configuration mode. From there, all the commands for the console line, covered mostly in Chapter 8, can be used. For example, the **login** and **password** *password* commands could be used to set up simple password checking when a user dials in.

Operational Status with the show version Command

Finally, one more command, the **show version** command, identifies a large number of important base features about a router. It does list the IOS version currently used by the router. However, it lists other important details as well: how long the router has been running, why the IOS was last reloaded, what file was used to load the IOS, and what interfaces are installed in the router. It also lists details about the amounts of NVRAM, RAM, and flash memory installed.

Example 15-5 shows an example, with the highlighted lines pointing out some of the more interesting features.

Example 15-5. Displaying IOS Version and Other Details with the show version ***Command***

[Click here to view code image](#)

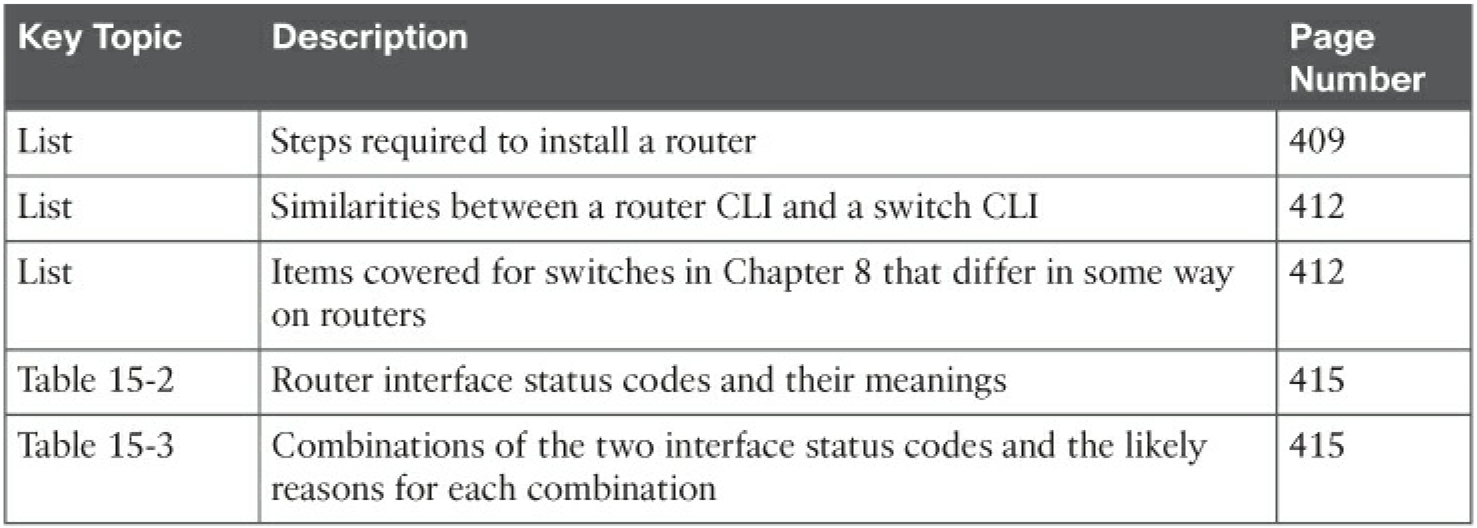
```
R1# show version
Cisco IOS Software, C2900 Software (C2900-UNIVERSALK9-M), Version 15.2(4)M1, RELEASE
SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2012 by Cisco Systems, Inc.
Compiled Thu 26-Jul-12 20:54 by prod_rel_team

ROM: System Bootstrap, Version 15.0(1r)M15, RELEASE SOFTWARE (fc1)

R1 uptime is 3 days, 4 hours, 19 minutes
System returned to ROM by reload at 14:00:46 UTC Sat Oct 13 2012
System image file is "flash:c2900-universalk9-mz.SPA.152-4.M1.bin"
Last reload type: Normal Reload
Last reload reason: Reload Command


! Legal notices omitted for brevity

If you require further assistance please contact us by sending email to
export@cisco.com.

Cisco CISCO2901/K9 (revision 1.0) with 483328K/40960K bytes of memory.
Processor board ID FTX1628838P
2 Gigabit Ethernet interfaces
4 Serial(sync/async) interfaces
1 terminal line
DRAM configuration is 64 bits wide with parity enabled.
255K bytes of non-volatile configuration memory.
3425968K bytes of USB Flash usbflash1 (Read/Write)
250880K bytes of ATA System CompactFlash 0 (Read/Write)


License Info:

! License information omitted for brevity

Configuration register is 0x2102
```

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. [Table 15-5](#) lists these key topics and where each is discussed.

Table 15-5. Key Topics for Chapter 15



Key Topic	Description	Page Number
List	Steps required to install a router	409
List	Similarities between a router CLI and a switch CLI	412
List	Items covered for switches in Chapter 8 that differ in some way on routers	412
Table 15-2	Router interface status codes and their meanings	415
Table 15-3	Combinations of the two interface status codes and the likely reasons for each combination	415

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, “Memory Tables,” or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, “Memory Tables Answer Key,” includes completed tables and lists for you to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

bandwidth
clock rate
IOS image

Command References

Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration commands (Table 15-6) and EXEC commands (Table 15-7) covered in this chapter. Practically speaking, you should memorize the commands as a complement to reading the chapter and doing all the activities in this exam preparation section. To check to see how well you have memorized the commands, cover the left side of the table with a piece of paper, read the descriptions on the right side, and see whether you remember the command.

Table 15-6. Chapter 15 Configuration Command Reference

Command	Description
interface *type number*	Global command that moves the user into configuration mode of the named interface.
ip address *address mask*	Interface subcommand that sets the router's IPv4 address and mask.
[no] shutdown	Interface subcommand that enables (**no shutdown**) or disables (**shutdown**) the interface.
duplex{ full | half | auto }	Interface command that sets the duplex, or sets the use of IEEE autonegotiation, for router LAN interfaces that support multiple speeds.
speed { 10 | 100 | 1000 }	Interface command for router Gigabit (10/100/1000) interfaces that sets the speed at which the router interface sends and receives data.
clock rate *rate*	Interface command that sets the speed at which the router supplies a clocking signal, applicable only when the router has a DCE cable installed. The unit is bits/second.
description *text*	An interface subcommand with which you can type a string of text to document information about that particular interface.

Table 15-7. Chapter 15 EXEC Command Reference

Command	Purpose
show interfaces *[type number]*	Lists a large set of informational messages about each interface, or about the one specifically listed interface.
show ip interface brief	Lists a single line of information about each interface, including the IP address, line and protocol status, and the method with which the address was configured (manual or DHCP).
show protocols *type number*	Lists information about the listed interface, including the IP address, mask, and line/protocol status.
show controllers *[type number]*	Lists many lines of information per interface, or for one interface, for the hardware controller of the interface. On serial interfaces, this command identifies the cable as either a DCE or DTE cable.
show version	Lists the version of IOS currently running in the router, plus a variety of other facts about the currently installed hardware and software in the router.

Chapter 16. Configuring IPv4 Addresses and Routes

This chapter covers the following exam topics:

- **Operation of IP Data Networks**
  - Predict the data flow between two hosts across a network.
- **IP Routing Technologies**
  - Describe basic routing concepts:
    - CEF
    - Packet forwarding
    - Router lookup process
  - Configure and verify utilizing the CLI to set basic Router configuration:
    - Cisco IOS commands to perform basic router setup
  - Configure and verify operation status of an ethernet interface
  - Verify router configuration and network connectivity
    - Cisco IOS commands to review basic router information and network connectivity
  - Configure and verify routing configuration for a static or default route given specific routing requirements
  - Differentiate methods of routing and routing protocols:
    - next hop
    - ip routing table
  - Configure and verify interVLAN routing (Router on a stick)
    - sub interfaces
    - upstream routing
    - encapsulation
  - Configure SVI interfaces

Routers route IPv4 packets. That simple statement actually carries a lot of hidden meaning. For routers to route packets, routers follow a routing process. That routing process relies on information called IP routes. Each IP route lists a destination—an IP network, IP subnet, or some other group of IP addresses. Each route also lists instructions that tell the router where to forward packets sent to addresses in that IP network or subnet. For routers to do a good job of routing packets, routers need to have a detailed accurate list of IP routes.

Routers use three methods to add IPv4 routes to their IPv4 routing tables. Routers first learn *connected routes*, which are routes for subnets attached to a router interface. Routers can also use *static routes*, which are routes created through a configuration command (**ip route**) that tells the router what route to put in the IPv4 routing table. And routers can use a routing protocol, in which routers tell each other about all their known routes, so that all routers can learn and build routes to all networks and subnets.

This chapter begins by reintroducing the IP routing process that relies on these routes. This IP routing discussion both reviews the concepts from Chapter 4, "Fundamentals of IPv4 Addressing and Routing," plus takes the concepts deeper, including showing information needed in a single IP route. Then, the second major heading in this chapter discusses connected routes, including variations of connected routes to VLANs connected to a router's VLAN trunk, and for connected routes on Layer 3 switches.

The final major section then looks at static routes, which let the engineer tell the router what route(s) to add to the router's IP routing table. The static route section also shows how to configure a static default route that is used when no other route matches an IP packet. Dynamic routing, using the Open Shortest Path First (OSPF) routing protocol, awaits in Chapter 17, "Learning IPv4 Routes with OSPFv2."

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 16-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping

Foundation Topics Section	Questions
IP Routing	1, 2
Configuring Connected Routes	3–5
Configuring Static Routes	6, 7

1. A PC opens a command prompt and uses the **ipconfig** command to see that the PC's IP address and mask are 192.168.4.77 and 255.255.255.224. The user then runs a test using the **ping 192.168.4.117** command. Which of the following answers is the most likely to happen?

   a. The PC sends packets directly to the host with address 192.168.4.117.

   b. The PC sends packets to its default gateway.

   c. The PC sends a DNS query for 192.168.4.117.

   d. The PC sends an ARP looking for the MAC address of the DHCP server.

2. Router R1 lists a route in its routing table. Which of the following answers list a fact from a route, that the router then compares to the packet's destination address? (Choose 2 answers.)

   a. Mask

   b. Next-hop router

   c. Subnet ID

   d. Outgoing interface

3. Router 1 has a Fast Ethernet interface 0/0 with IP address 10.1.1.1. The interface is connected to a switch. This connection is then migrated to use 802.1Q trunking. Which of the following commands could be part of a valid configuration for Router 1's Fa0/0 interface? (Choose two answers.)

   a. interface fastethernet 0/0.4

   b. dot1q enable

   c. dot1q enable 4

   d. trunking enable

   e. trunking enable 4

   f. encapsulation dot1q 4

4. A router is configured with the **no ip subnet-zero** global configuration command. Which of the following interface subcommands would not be accepted by this router?

   a. ip address 10.1.1.1 255.255.255.0

   b. ip address 10.0.0.129 255.255.255.128

   c. ip address 10.1.2.2 255.254.0.0

   d. ip address 10.0.0.5 255.255.255.252

5. A Layer 3 switch has been configured to route IP packets between VLANs 1, 2, and 3, which connect to subnets 172.20.1.0/25, 172.20.2.0/25, and 172.20.3.0/25, respectively. The engineer issues a **show ip route** command on the Layer 3 switch, listing the connected routes. Which of the following answers lists a piece of information that should be in at least one of the routes?

   a. Interface Gigabit Ethernet 0/0.3

   b. Next-hop router 172.20.4.1

   c. Interface VLAN 2

   d. Mask 255.255.255.0

6. An engineer configures a static IPv4 route on Router R1. Which of the following pieces of information should not be listed as a parameter in the configuration command that creates this static IPv4 route?

   a. The destination subnet's subnet ID

   b. The next-hop router's IP address

   c. The next-hop router's neighboring interface

   d. The subnet mask

7. Which of the following commands correctly configures a static route?

   a. ip route 10.1.3.0 255.255.255.0 10.1.130.253

   b. ip route 10.1.3.0 serial 0

   c. ip route 10.1.3.0 /24 10.1.130.253

   d. ip route 10.1.3.0 /24 serial 0

Answers to the "Do I Know This Already?" quiz:

1 B 2 A and C 3 A and F 4 C 5 C 6 C 7 A

Foundation Topics

IP Routing

IP routing—the process of forwarding IP packets—delivers packets across entire TCP/IP networks, from the device that originally builds the IP packet to the device that is supposed to receive the packet. In other words, IP routing delivers IP packets from the sending host to the destination host.

The complete end-to-end routing process relies on network layer logic on hosts and on routers. The sending host uses Layer 3 concepts to create an IP packet, forwarding the IP packet to the host's default gateway (default router). The process requires Layer 3 logic on the routers as well, by which the routers compare the destination address in the packet to their routing tables, to decide where to forward the IP packet next.

The routing process also relies on data link and physical details at each link. IP routing relies on serial links, Ethernet LANs, wireless LANs, and many other networks that implement data link and physical layer standards. These lower-layer devices and protocols move the IP packets around the TCP/IP network by encapsulating and transmitting the packets inside data link layer frames.

Those previous two paragraphs summarize the key concepts about IP routing as introduced back in Chapter 4. Next, this section reviews IP routing, while taking the discussion another step or two deeper, taking advantage of the additional depth of knowledge discussed in Parts II and III of this book.

> **Note**
>
> Some references also incorrectly claim that the term "IP routing" includes the function of dynamically learning routes with IP routing protocols. While IP routing protocols play an important role, the term "IP routing" refers to the packet-forwarding process only.

IPv4 Routing Process Reference

Because you have already seen the basics back in Chapter 4, this section collects the routing process into steps for reference. The steps use many specific terms discussed in Parts II and III of this book. The upcoming descriptions and example then discuss these summaries of routing logic to make sure that each step is clear.

The routing process starts with the host that creates the IP packet. First, the host asks the question: Is the destination IP address of this new packet in my local subnet? The host uses its own IP address/mask to determine the range of addresses in the local subnet. Based on its own opinion of the range of addresses in the local subnet, a LANbased host acts as follows:

Key Topic

Step 1. If the destination is local, send directly:

- **A.** Find the destination host's MAC address. Use the already-known Address Resolution Protocol (ARP) table entry, or use ARP messages to learn the information.
- **B.** Encapsulate the IP packet in a data link frame, with the destination data link address of the *destination host*.

Step 2. If the destination is not local, send to the default gateway:

- **A.** Find the default gateway's MAC address. Use the already-known ARP table entry, or use ARP messages to learn the information.
- **B.** Encapsulate the IP packet in a data link frame, with the destination data link address of the *default gateway*.

Figure 16-1 summarizes these same concepts. In the figure, host A sends a local packet directly to host D. However, for packets to host B, on the other side of a router and therefore in a different subnet, host A sends the packet to its default router (R1). (As a reminder, the terms *default gateway* and *default router* are synonyms.)

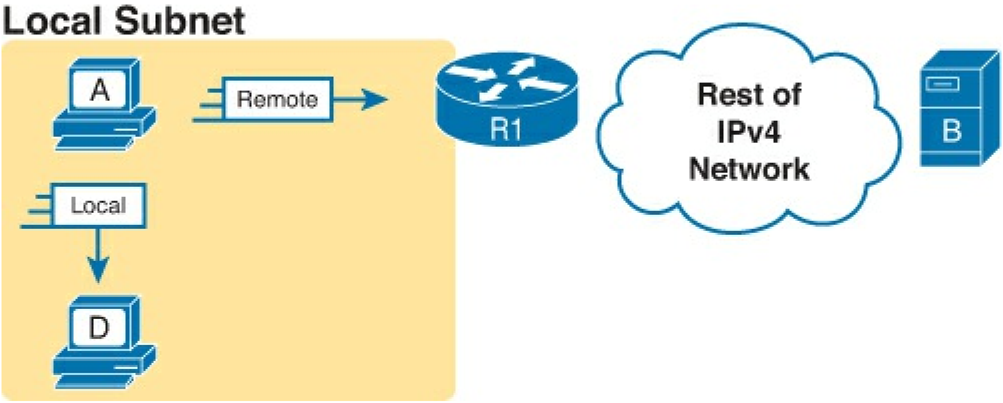


Figure 16-1. Host Routing Logic Summary

Routers have a little more routing work to do as compared with hosts. While the host logic began with an IP packet sitting in memory, a router has some work to do before getting to that point. With the following five-step summary of a router's routing logic, the router takes the first two steps just to receive the frame and extract the IP packet, before thinking about the packet's destination address at Step 3. The steps are as follows:

1. For each received data link frame, choose whether or not to process the frame. Process it if:
    - **A.** The frame has no errors (per the data link trailer Frame Check Sequence, or FCS, field)
    - **B.** The frame's destination data link address is the router's address (or an appropriate multicast or broadcast address).
2. If choosing to process the frame at Step 1, deencapsulate the packet from inside the data link frame.
3. Make a routing decision. To do so, compare the packet's destination IP address to the routing table and find the route that matches the destination address. This route identifies the outgoing interface of the router and possibly the next-hop router.
4. Encapsulate the packet into a data link frame appropriate for the outgoing interface. When forwarding out LAN interfaces, use ARP as needed to find the next device's MAC address.
5. Transmit the frame out the outgoing interface, as listed in the matched IP route.

Note

The fact that this list has five steps, instead of breaking the logic into some other number of steps, does not matter. The concepts inside each step matter a lot—know them—but for the exams, there is no need to memorize which piece of logic goes with a particular step number.

This routing process summary lists many details, but sometimes you can think about the routing process in simpler terms. For example, leaving out some details, this paraphrase of the step list details the same big concepts:

> The router receives a frame, removes the packet from inside the frame, decides where to forward the packet, puts the packet into another frame, and sends the frame.

To give you a little more perspective on these steps, Figure 16-2 breaks down the same five-step routing process as a diagram. The figure shows a packet arriving from the left, entering a router Ethernet interface, with an IP destination of host C. The figure shows the packet arriving, encapsulated inside an Ethernet frame (both header and trailer).

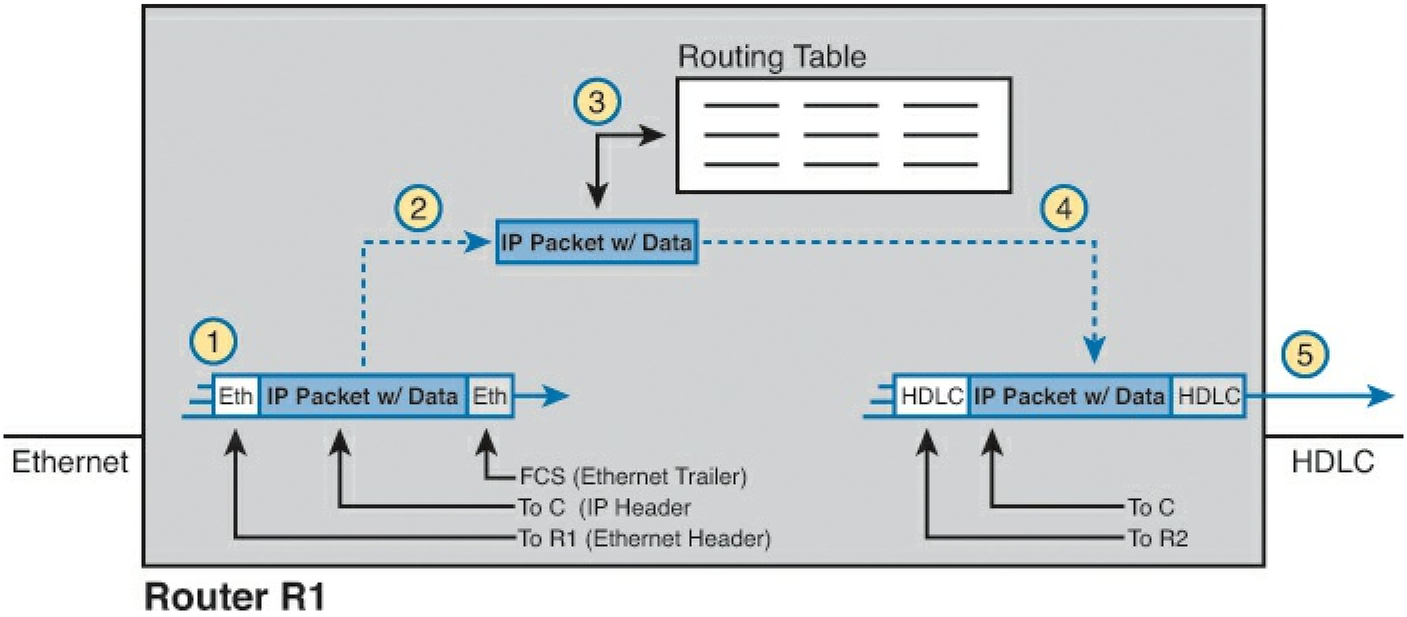


Figure 16-2. Router Routing Logic Summary

Router R1 processes the frame and packet as shown with the numbers in the figure, matching the same five-step process describe just before the figure, as follows:

1. Router R1 notes that the received Ethernet frame passes the FCS check, and that the destination Ethernet MAC address is R1's MAC address, so R1 processes the frame.
2. R1 deencapsulates the IP packet from inside the Ethernet frame's header and trailer.
3. R1 compares the IP packet's destination IP address to R1's IP routing table.
4. R1 encapsulates the IP packet inside a new data link frame, in this case, inside a High-Level Data Link Control (HDLC) header and trailer.
5. R1 transmits the IP packet, inside the new HDLC frame, out the serial link on the right.

Note

This chapter uses several figures that show an IP packet encapsulated inside a data link layer frame. These figures often show both the data link header as well as the data link trailer, with the IP packet in the middle. The IP packets all include the IP header, plus any encapsulated data.

An Example of IP Routing

The next several pages walk you through an example that discusses each routing step, in order, through multiple devices. That example uses a case in which host A (172.16.1.9) sends a packet to host B (172.16.2.9), with host routing logic and the five steps showing how R1 forwards the packet.

Figure 16-3 shows a typical IP addressing diagram for an IPv4 network with typical address abbreviations. The diagram can get a little too messy if it lists the full IP address for every router interface. When possible, these diagrams usually list the subnet, and then the last octet or two of the individual IP addresses—just enough so that you know the IP address, but with less clutter. For example, host A uses IP address 172.16.1.9, taking from subnet 172.16.1.0/24 (in which all addresses begin 172.16.1), and the ".9" beside the host A icon. As another example, R1 uses address 172.16.1.1 on its LAN interface, 172.16.4.1 on one serial interface, and 172.16.5.1 on the other serial interface.

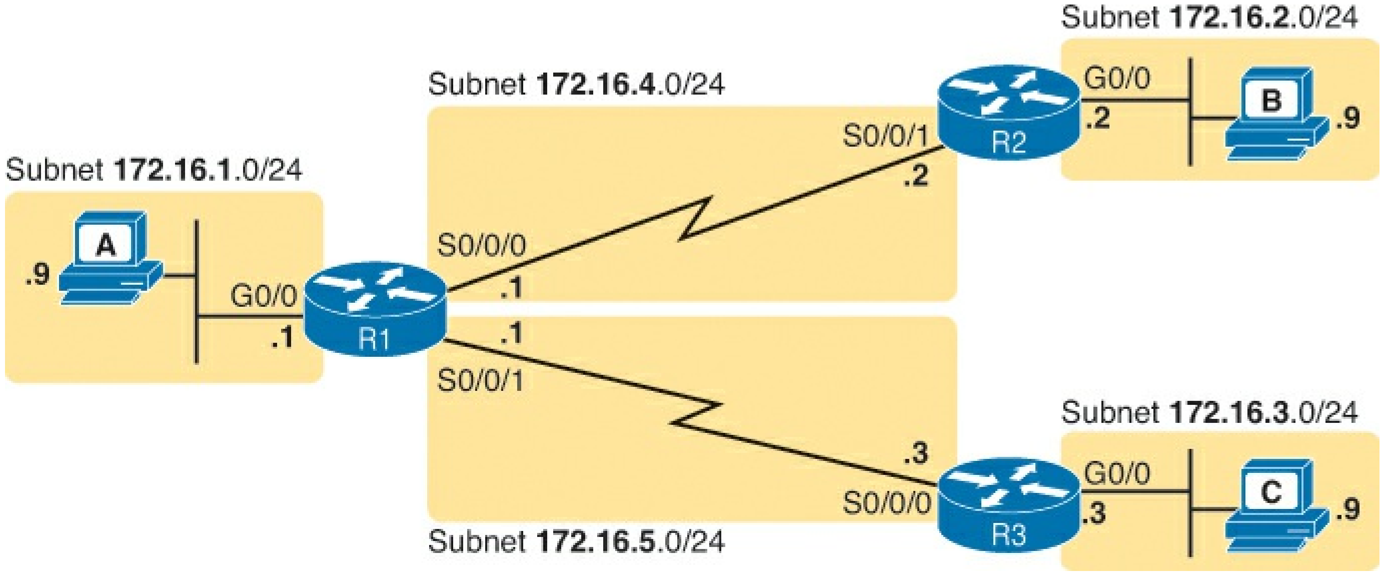

Subnet 172.16.2.0/24
Subnet 172.16.4.0/24
Subnet 172.16.1.0/24
G0/0
.2
B
.9
S0/0/1
R2
.2
A
.9
S0/0/0
G0/0
.1
.1
R1
.1
S0/0/1
Subnet 172.16.3.0/24
.3
G0/0
C
S0/0/0
.3
.9
R3
Subnet 172.16.5.0/24

Figure 16-3. IPv4 Network Used to Show Five-Step Routing Example

Now on to the example, with host A (172.16.1.9) sending a packet to host B (172.16.2.9).

Host Forwards the IP Packet to the Default Router (Gateway)

In this example, host A uses some application that sends data to host B (172.16.2.9). After host A has the IP packet sitting in memory, host A's logic reduces to the following:

- My IP address/mask is 172.16.1.9/24, so my local subnet contains numbers 172.16.1.0–172.16.1.255 (including the subnet ID and subnet broadcast address).
- The destination address is 172.16.2.9, which is clearly not in my local subnet.
- Send the packet to my default gateway, which is set to 172.16.1.1.
- To send the packet, encapsulate it in an Ethernet frame. Make the destination MAC address be R1's G0/0 MAC address (host A's default gateway).

Figure 16-4 pulls these concepts together, showing the destination IP address and destination MAC address in the frame and packet sent by host A in this case.

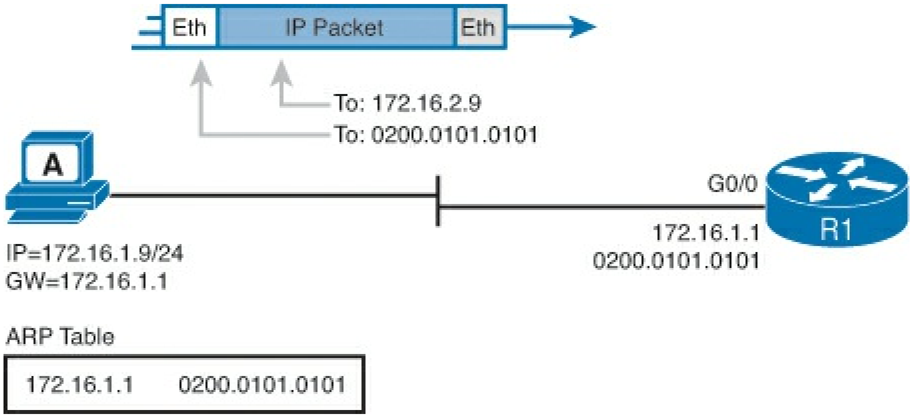

Eth
IP Packet
Eth
To: 172.16.2.9
To: 0200.0101.0101
A
G0/0
R1
172.16.1.1
0200.0101.0101
IP=172.16.1.9/24
GW=172.16.1.1
ARP Table
172.16.1.1 0200.0101.0101

Figure 16-4. Host A Sends Packet to Host B

Note that the figure shows the Ethernet LAN as simple lines, but the LAN can include any of the devices discussed in Part II of this book. The LAN could be a single cable between host A and R1, or it could be 100 LAN switches connected across a huge campus of buildings. Regardless, host A and R1 sit in the same VLAN, and the Ethernet LAN then delivers the Ethernet frame to R1's G0/0 interface.

Routing Step 1: Decide Whether to Process the Incoming Frame

Routers receive many frames in an interface, particular LAN interfaces. However, a router can and should ignore some of those frames. So, the first step in the routing process begins with a decision of whether a router should process the frame or silently discard (ignore) the frame.

First, the router does a simple but important check (Step 1A in the process summary) so that the router ignores all frames that had bit errors during transmission. The router uses the data link header's FCS field to check the frame, and if errors occurred in transmission, the router discards the frame. (The router makes no attempt at error recovery; that is, the router does not ask the sender to retransmit the data.)

The router also checks the destination data link address (Step 1B in the summary) to decide whether the frame is intended for the router. For example, frames sent to the router's unicast MAC address for that interface are clearly sent to that router. However, a router can actually receive a frame sent to some other unicast MAC address, and routers should ignore these frames.

For example, routers will receive some unicast frames sent to other devices in the VLAN just because of how LAN switches work. Think back to how LAN switches forward unknown unicast frames: frames for which the switch does not list the destination MAC address in the MAC address table. The LAN switch floods those frames. The result? Routers sometimes receive frames destined for some other device, with some other device's MAC address listed as the destination MAC address. Routers should ignore those frames.

In this example, host A sends a frame destined for R1's MAC address. So, after the frame is received, and after R1 confirms with the FCS that no errors occurred, R1 confirms that the frame is destined for R1's MAC address (0200.0101.0101 in this case). All checks have been passed, so R1 will process the frame, as shown in Figure 16-5. (Note that the large rectangle in the figure represents the internals of Router R1.)

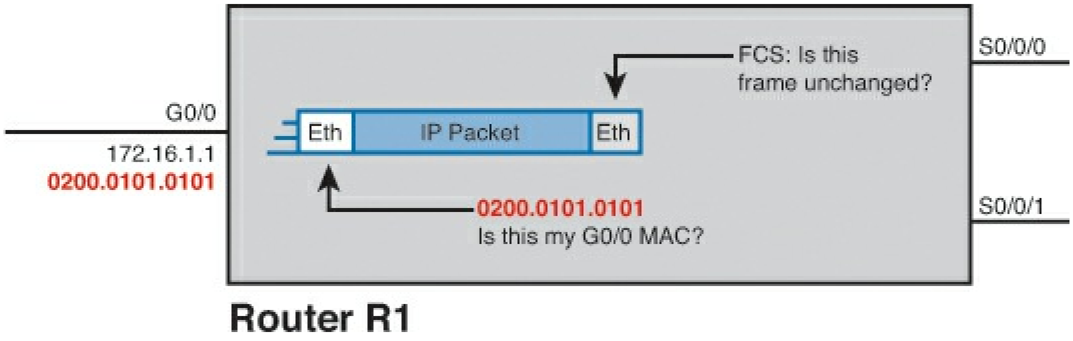


Figure 16-5. Routing Step 1, on Router R1: Checking FCS and Destination MAC

Routing Step 2: Deencapsulation of the IP Packet

After the router knows that it ought to process the received frame (per Step 1), the next step is a relatively simple step: deencapsulating the packet. In router memory, the router no longer needs the original frame's data link header and trailer, so the router removes and discards them, leaving the IP packet, as shown in Figure 16-6. Note that the destination IP address remains unchanged (172.16.2.9).

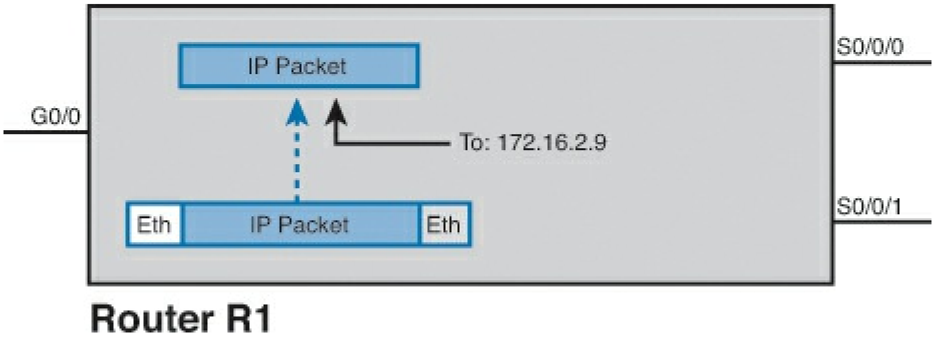


Figure 16-6. Routing Step 2 on Router R1: Deencapsulating the Packet

Routing Step 3: Choosing Where to Forward the Packet

While routing Step 2 required little thought, Step 3 requires the most thought of all the steps. At this point, the router needs to make a choice about where to forward the packet next. That process uses the router's IP routing table, with some matching logic to compare the packet's destination address with the table.

First, an IP routing table lists multiple routes. Each individual route contains several facts, which in turn can be grouped as shown in Figure 16-7. Part of each route is used to match the destination address of the packet, while the rest of the route lists forwarding instructions: where to send the packet next.

Key Topic

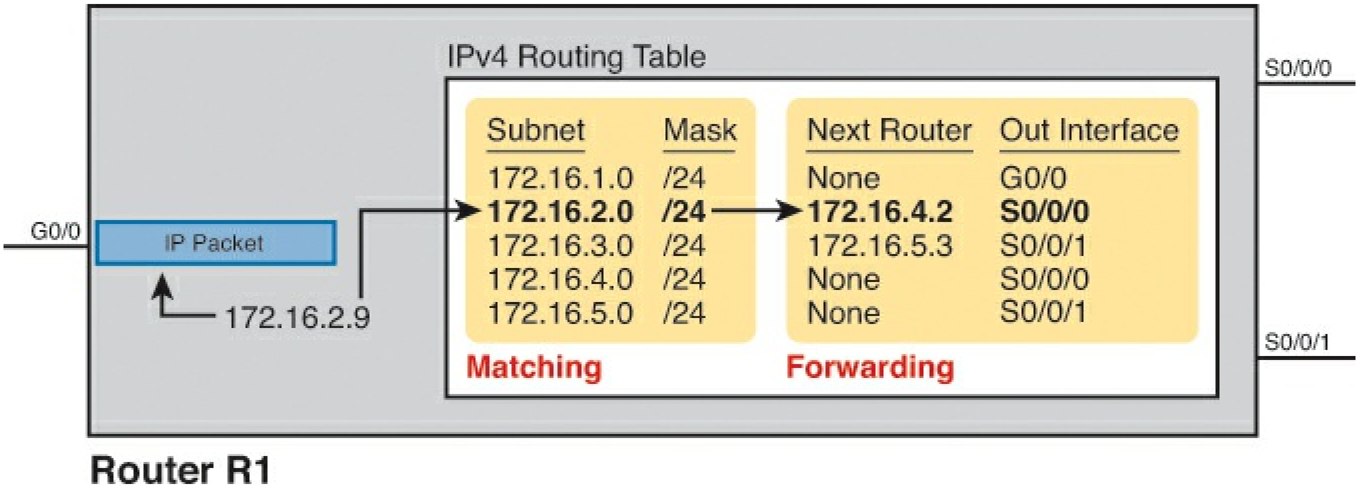


Figure 16-7. Routing Step 3 on Router R1: Matching the Routing Table

Focus on the entire routing table for a moment, and notice the fact that it lists five routes. Earlier, Figure 16-3 shows the entire example network, with five subnets, so R1 has a route for each of the five subnets.

Next, look at the part of the five routes that Router R1 will use to match packets. To fully define each subnet, each route lists both the subnet ID and the subnet mask. When matching the IP packet's destination with the routing table, the router looks at the packet's destination IP address (172.16.2.9) and compares it to the range of addresses defined by each subnet. Specifically, the router looks at the subnet and mask information, which with a little math, the router can figure out in which of those subnets 172.16.2.9 resides (the route for subnet 172.16.2.0/24).

Finally, look to the right side of the figure, to the forwarding instructions for these five routes. After the router matches a specific route, the router uses the forwarding information in the route to tell the router where to send the packet next. In this case, the router matched the route for subnet 172.16.2.0/24, so R1 will forward the packet out its own interface S0/0/0, to Router R2 next, listed with its next-hop router IP address of 172.16.4.2.

Note

Routes for remote subnets typically list both an outgoing interface and next-hop router IP address. Routes for subnets that connect directly to the router list only the outgoing interface, because packets to these destinations do not need to be sent to another router.

Routing Step 4: Encapsulating the Packet in a New Frame

At this point, the router knows how it will forward the packet. However, routers cannot forward a packet without first wrapping a data link header and trailer around it (encapsulation).

Encapsulating packets for serial links does not require a lot of thought, because of the simplicity of the HDLC and PPP protocols. As discussed back in Chapter 3, "Fundamentals of WANs," because serial links have only two devices on the link—the sender and the then-obvious receiver—the data link addressing does not matter. In this example, R1 forwards the packet out S0/0/0, after encapsulating the packet inside an HDLC frame, as shown in Figure 16-8.

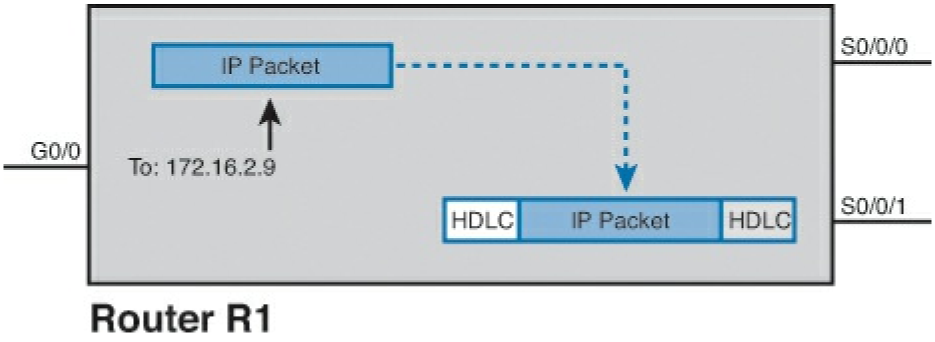


Figure 16-8. Routing Step 4 on Router R1: Encapsulating the Packet

Note that with some other types of data links, the router has a little more work to do at this routing step. For example, sometimes a router forwards packets out an Ethernet interface. To encapsulate the IP packet, the router would need to build an Ethernet header, and that Ethernet header's destination MAC address would need to list the correct value.

For example, consider this different sample network, with an Ethernet WAN link between Routers R1 and R2. R1 matches a route that tells R1 to forward the packet out R1's G0/1 Ethernet interface to 172.16.6.2 (R2) next. R1 needs to put R2's MAC address in the header, and to do that, R1 uses its IP ARP table information, as seen in Figure 16-9. If R1 did not have an ARP table entry for 172.16.6.2, R1 would first have to use ARP to learn the matching MAC address.

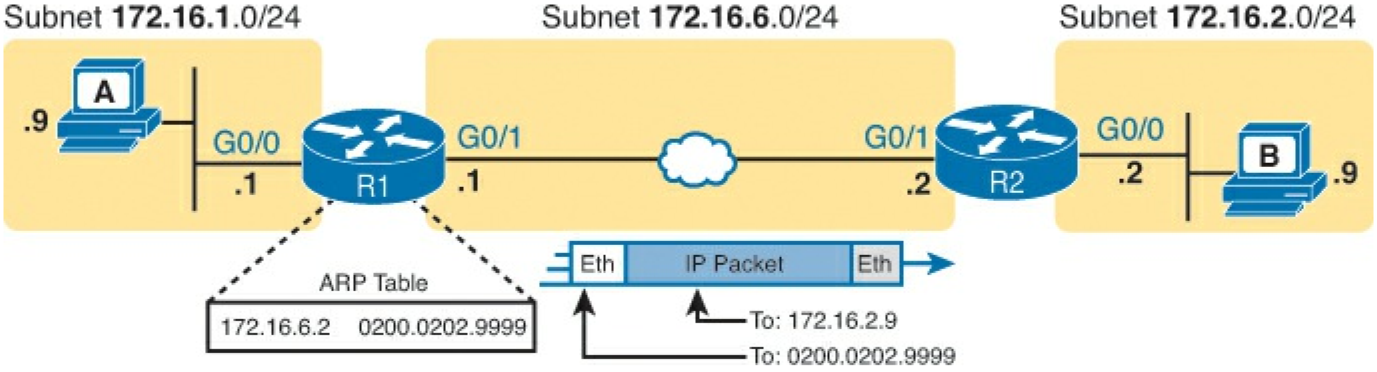


Figure 16-9. Routing Step 4 on Router R1 with a LAN Outgoing Interface

Routing Step 5: Transmitting the Frame

After the frame has been prepared, the router simply needs to transmit the frame. The router might have to wait, particularly if other frames are already waiting their turn to exit the interface.

Internal Processing on Cisco Routers

The discussion so far in this chapter explains one way to think about how a host and a router do their work internally. However, for Cisco to compete well in the router marketplace, it must be ready to make its routers perform that routing process well, and quickly, in all kinds of environments. If not, Cisco competitors could argue that their routers performed better, could route more packets per second (pps), and could win business away from Cisco.

This next topic looks a little deeper at how Cisco actually implements IP routing internal to a router. The discussion so far in this chapter was fairly generic, but it matches an early type of internal processing on Cisco routers called *process switching*. This section discusses the issues that drove Cisco to improve the internal routing process, while having the same result: A packet arrives inside one frame, a choice is made, and it exits the router inside another frame.

Potential Routing Performance Issues

When learning about IP routing, it helps to think through all the particulars of the routing process, as discussed over the last five or so pages. However, routers barely spend any processing time to route a single IP packet. In fact, even slower routers need to forward tens of thousands of packets per second (pps); to do that, the routers cannot spend a lot of effort processing each packet.

The process of matching a packet's destination address with the IP routing table can actually take a lot of CPU time. The example in this chapter (Figure 16-7) listed only five routes, but enterprise networks routinely have thousands of IP routes, while routers in the core of the Internet have hundreds of thousands of routes. Now think about a router CPU that needs to search a list 100,000 entries long, for every packet, for a router that needed to forward hundreds of thousands of packets per second! And what if the router had to do subnetting math each time, calculating the range of addresses in each subnet for each route? Those actions would take too many CPU cycles.

Over the years, Cisco has created several ways to optimize the internal process of how routers forward packets. Some methods tie to a specific model series of router. Layer 3 switches do the forwarding in Application Specific Integrated Circuits (ASIC), which are computer chips built for the purpose of forwarding frames or packets. All these optimizations take the basic logic from the five-step list here in the book, but work differently inside the router hardware and software, in an effort to use fewer CPU cycles and reduce the overhead of forwarding IP packets.

Cisco Router Fast Switching and CEF

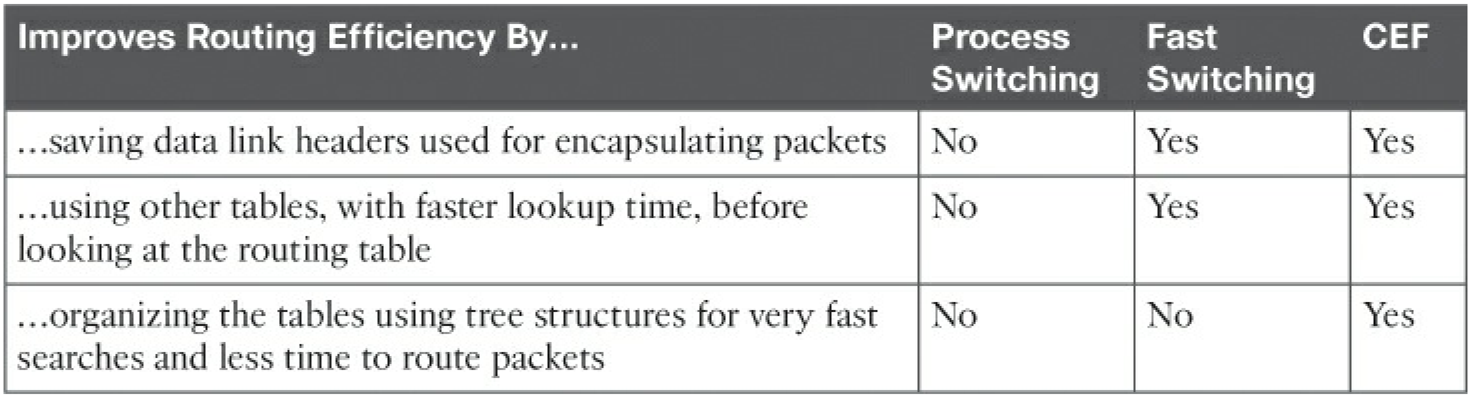
Historically speaking, Cisco has had three major variations of internal routing logic that apply across the entire router product family. First, Cisco routers used internal logic called *process switching* in the early days of Cisco routers, dating back to the late 1980s and early 1990s. Process switching works basically like the routing process detailed so far in this chapter, without any of the extra optimizations.

Next, in the early 1990s, Cisco introduced alternate internal routing logic called *fast switching*. Fast switching made a couple of optimizations compared to the older process-switching logic. First, it kept another list in addition to the routing table, listing specific IP addresses for recently forwarded packets. This fast-switching cache also kept a copy of the new data link headers used when forwarding packets to each destination, so rather than build a new data link header for each packet destined for a particular IP address, the router saved a little effort by copying the old data link header.

Cisco improved over fast switching with the introduction of Cisco Express Forwarding (CEF) later in the 1990s. Like fast switching, CEF uses additional tables for faster searches, and it saves outgoing data link headers. However, CEF organizes its tables for all routing table destinations, ahead of time, not just for some of the specific destination IP addresses. CEF also uses much more sophisticated search algorithms and binary tree structures as compared to fast switching. As a result, the CEF table lookups that replace the routing table matches take even less time than with fast switching. And it caches the data link headers as well.

Today, current models of Cisco routers, and current IOS versions, use CEF by default. Table 16-2 lists a summary of the key comparison points between process switching, fast switching, and CEF.

Table 16-2. Comparisons of Packet Switching, Fast Switching, and CEF



Improves Routing Efficiency By...	Process Switching	Fast Switching	CEF
...saving data link headers used for encapsulating packets	No	Yes	Yes
...using other tables, with faster lookup time, before looking at the routing table	No	Yes	Yes
...organizing the tables using tree structures for very fast searches and less time to route packets	No	No	Yes

Configuring Connected Routes

Cisco routers enable IPv4 routing globally, by default. Then, to make the router be ready to route packets on a particular interface, the router must be configured with an IP address and the interface must be configured such that it comes up, reaching a "line status up, line protocol up" state. Only at that point can routers route IP packets in and out a particular interface.

After a router can route IP packets out one or more interfaces, the router needs some routes. Routers can add routes to their routing tables through three methods:

Key Topic

Connected routes: Added because of the configuration of the **ip address** interface subcommand on the local router

Static routes: Added because of the configuration of the **ip route** global command on the local router

Routing protocols: Added as a function by configuration on all routers, resulting in a process by which routers dynamically tell each other about the network so that they all learn routes

This second of three sections discusses several variations on how to configure connected routes, while the last major section discusses static routes.

Connected Routes and the ip address Command

A Cisco router automatically adds a route to its routing table for the subnet connected to each interface, assuming that the following two facts are true:

Key Topic

- The interface is in a working state—in other words, the interface status in the **show interfaces** command lists a line status of up and a protocol status of up.
- The interface has an IP address assigned through the **ip address** interface subcommand.

The concept of connected routes is relatively basic. The router of course needs to know the subnet number used on the physical network connected to each of its interfaces, so the router can route packets to that subnet. The router can simply do the math, taking the interface IP address and mask, and calculate the subnet ID. However, the router only needs that route when the interface is up and working, so the router includes a connected route in the routing table only when the interface is working.

Example 16-1 shows the connected routes on Router R1 in Figure 16-10. The figure repeats the same IP network shown earlier in the routing example. The first part of the example shows the configuration of IP addresses on all three of R1's interfaces. The end of the examples lists the output from the **show ip route** command, which lists these routes with a *c* as the route code, meaning *connected*.

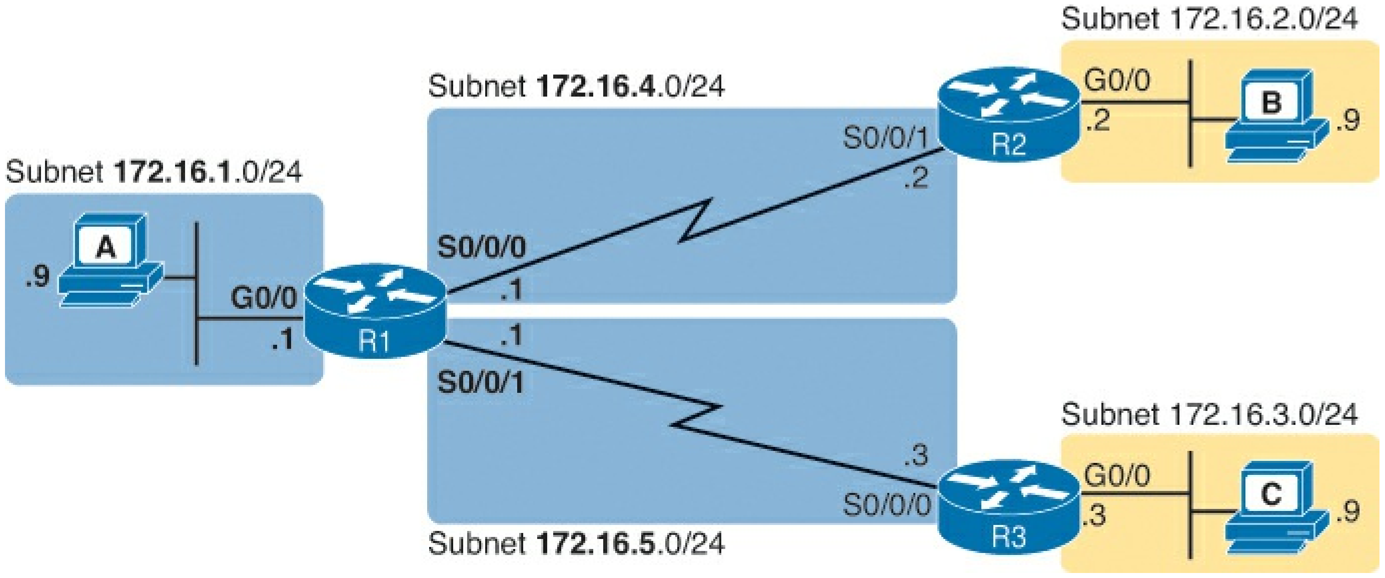


Figure 16-10. Sample Network to Show Connected Routes

Example 16-1. Connected and Local Routes on Router R1

Click here to view code image

```
! Excerpt from show running-config follows...
!
interface GigabitEthernet0/0
ip address 172.16.1.1 255.255.255.0
!
interface Serial0/0/0
ip address 172.16.4.1 255.255.255.0
!
interface Serial0/0/1
ip address 172.16.5.1 255.255.255.0

R1# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
E1 - OSPF external type 1, E2 - OSPF external type 2
i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
ia - IS-IS inter area, * - candidate default, U - per-user static route
o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
+ - replicated route, % - next hop override

Gateway of last resort is not set

172.16.0.0/16 is variably subnetted, 6 subnets, 2 masks
C 172.16.1.0/24 is directly connected, GigabitEthernet0/0
L 172.16.1.1/32 is directly connected, GigabitEthernet0/0
C 172.16.4.0/24 is directly connected, Serial0/0/0
L 172.16.4.1/32 is directly connected, Serial0/0/0
C 172.16.5.0/24 is directly connected, Serial0/0/1
L 172.16.5.1/32 is directly connected, Serial0/0/1
```

Take a moment to look closely at each of the three highlighted routes in the output of **show ip route**. Each lists a C in the first column, and each has text that says "directly connected"; both identify the route as connected to the router. The early part of each route lists the matching parameters (subnet ID and mask), as shown in the earlier example in Figure 16-7. The end of each of these routes lists the outgoing interface.

Note that the router also automatically produces a different kind of route, called a *local route*. The local routes define a route for the one specific IP address configured on the router interface. Each local route has a /32 prefix length, defining a *host route*, which defines a route just for that one IP address. For example, the last local route, for 172.16.5.1/32, defines a route that matches only the IP address of 172.16.5.1. Routers use these local routes that list their own local IP addresses to more efficiently forward packets sent to the router itself.

After a router has added these connected routes, the router can route IPv4 packets between those subnets.

Routing Between Subnets on VLANs

Almost all enterprise networks use VLANs. To route IP packets in and out of those VLANs—or more accurately, the subnets that sit on each those VLANs—some router needs to have an IP address in each subnet and have a connected route to each of those subnets. Then the hosts in each subnet can use the router IP addresses as their default gateways, respectively.

Three options exist for connecting a router to each subnet on a VLAN. However, the first option requires too many interfaces and links, and is only mentioned to make the list complete:

Key Topic

- Use a router, with one router LAN interface and cable connected to the switch for each and every VLAN (typically not used).
- Use a router, with a VLAN trunk connecting to a LAN switch.
- Use a Layer 3 switch.

Figure 16-11 shows an example network where the second and third options both happen to be used. The figure shows a central site campus LAN on the left, with 12 VLANs. At the central site, two of the switches act as Layer 3 switches, combining the functions of a router and a switch, routing between all 12 subnets/VLANs. The remote branch sites on the right side of the figure each use two VLANs; each router uses a VLAN trunk to connect to and route for both VLANs.

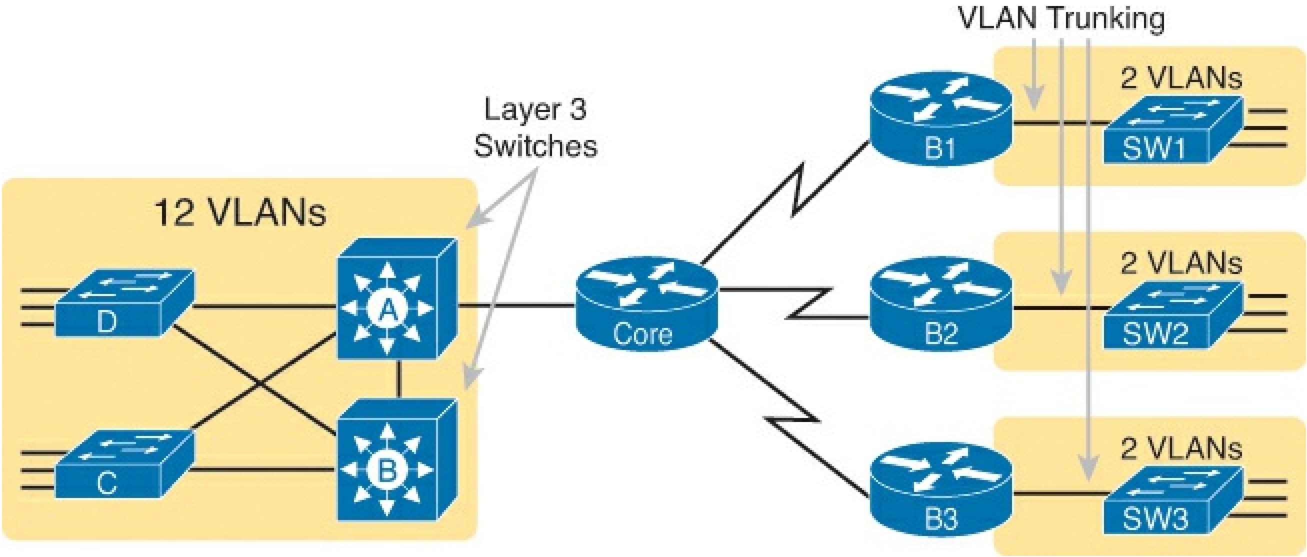


Figure 16-11. Subinterfaces on Router R1

Note that Figure 16-11 just shows an example. The engineer could use Layer 3 switching at each site, or routers with VLAN trunking at each site. This chapter focuses more on the details of how to configure the features, as discussed in the next few pages.

Configuring Routing to VLANs using 802.1Q on Routers

This next topic discusses how to route packets to subnets associated with VLANs connected to a router 802.1Q trunk. That long description can be a bit of a chore to repeat each time someone wants to discuss this feature, so over time, the networking world has instead settled on a shorter and more interesting name for this feature: Router on a Stick (ROAS).

ROAS uses router VLAN trunking configuration to give the router a logical router interface connected to each VLAN, and therefore each subnet that sits on a separate VLAN. That trunking configuration revolves around *subinterfaces*. The router needs to have an IP address/mask associated with each VLAN on the trunk. However, the router uses only one physical interface on which to configure the **ip address** command. Cisco solves this problem by creating multiple virtual router interfaces, one associated with each VLAN on that trunk (at least for each VLAN that you want the trunk to support). Cisco calls these virtual interfaces *subinterfaces*.

The ROAS configuration creates a subinterface for each VLAN on the trunk, and the router then treats all frames tagged with that associated VLAN ID as if they came in or out of that subinterface. Figure 16-12 shows the concept with Router B1, one of the branch routers from Figure 16-11. Because this router needs to route between only two VLANs, the figure also shows two subinterfaces, named G0/0.10 and G0/0.20, which create a new place in the configuration where the per-VLAN configuration settings can be made. The router treats frames tagged with VLAN 10 as if they came in or out of G0/0.10, and frames tagged with VLAN 20 as if they came in or out VLAN 20.

Key Topic

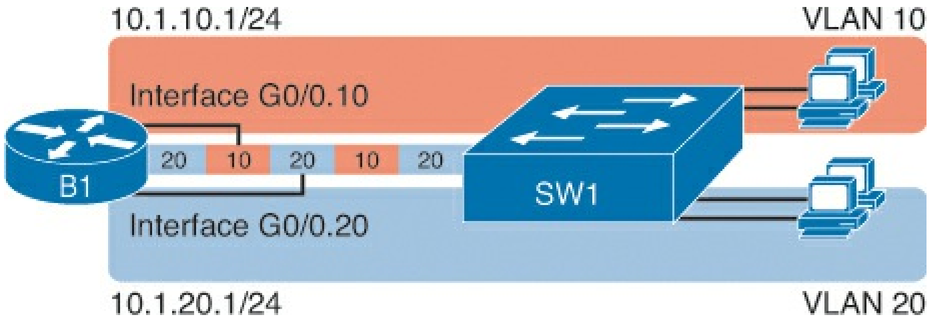


Figure 16-12. Subinterfaces on Router B1

Additionally, note that Cisco routers do not attempt to negotiate trunking, so both the router and switch need to manually configure trunking. This chapter discusses the router side of that trunking configuration; the matching switch interface would need to be configured with the **switchport mode trunk** command.

Example 16-2 shows a full example of the 802.1Q trunking configuration required on Router B1 in the figure. More generally, these steps detail how to configure 802.1Q trunking on a router:

Key Topic

Step 1. Create a unique subinterface for each VLAN that needs to be routed (**interface** *type number.subint*).

Step 2. Enable 802.1Q, and associate one specific VLAN with the subinterface in subinterface config mode (**encapsulation dot1q** *vlan_id*).

Step 3. Configure IP settings (address and mask) in subinterface config mode (**ip address** *address mask*).

Example 16-2. Router Configuration for the 802.1Q Encapsulation Shown in Figure 16-12

Click here to view code image

```
B1# show running-config
! Only pertinent lines shown
interface gigabitethernet 0/0
! No IP address up here! No encapsulation up here!
!
interface gigabitethernet 0/0.10
encapsulation dot1q 10
ip address 10.1.10.1 255.255.255.0
!
interface gigabitethernet 0/0.20
encapsulation dot1q 20
ip address 10.1.20.1 255.255.255.0
!
B1# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
! Lines omitted for brevity

10.0.0.0/8 is variably subnetted, 4 subnets, 2 masks
C 10.1.10.0/24 is directly connected, GigabitEthernet0/0.10
L 10.1.10.1/32 is directly connected, GigabitEthernet0/0.10
C 10.1.20.0/24 is directly connected, GigabitEthernet0/0.20
L 10.1.20.1/32 is directly connected, GigabitEthernet0/0.20
```

First, look at the subinterface numbers. The subinterface number begins with the period, like .10 and .20 in this case. These numbers can be any number from 1 up through a very large number (over 4 billion). The number just needs to be unique among all subinterfaces associated with this one physical interface. In fact, the subinterface number does not even have to match the associated VLAN ID. (The **encapsulation** command, and not the subinterface number, defines the VLAN ID associated with the subinterface.)

> **Note**
>
> While not required, most sites do choose to make the subinterface number match the VLAN ID, as shown in Example 16-2, just to avoid confusion.

Each subinterface configuration lists two subcommands. One command (**encapsulation**) enables trunking and defines the VLAN whose frames are considered to be coming in and out of the subinterface. The **ip address** command works the same way it does on any other interface. Note that if the physical Ethernet interface reaches an up/up state, the subinterface should as well, which would then let the router add the connected routes shown at the bottom of the example.

Now that the router has a working interface, with IPv4 addresses configured, the router can route IPv4 packets on these subinterfaces. That is, the router treats these subinterfaces like any physical interface in terms of adding connected routes, matching those routes and forwarding packets to/from those connected subnets.

> **Note**
>
> As a brief aside, while Example 16-2 shows 802.1Q configuration, the ISL configuration on the same router would be practically identical. Just substitute the keyword **isl** instead of **dot1q** in each case.

While Example 16-2 shows one way to configure ROAS on a router, that particular example avoids using the native VLAN. However, each 802.1Q trunk has one native VLAN, and when used, the configuration to use that native VLAN differs, with two options for the router side of the configuration:

Key Topic

- Configure the **ip address** command on the physical interface, but without an **encapsulation** command; the router considers this physical interface to be using the native VLAN.
- Configure the **ip address** command on a subinterface, and use the **encapsulation...native** subcommand.

Example 16-3 shows both configuration options with a small change to the same configuration in Example 16-2. In this case, VLAN 10 becomes the native VLAN. The top part of the example shows the option to configure the router to use native VLAN 10, assuming that the switch also has been configured to use native VLAN 10 as well. The second half of the example shows how to configure that same native VLAN on a subinterface.

Example 16-3. Router Configuration Using Native VLAN 10 on Router B1

Click here to view code image

```
! First option: put the native VLAN IP address on the
! physical interface
interface gigabitethernet 0/0
ip address 10.1.10.1 255.255.255.0
!
interface gigabitethernet 0/0.20
encapsulation dot1q 20
ip address 10.1.20.1 255.255.255.0
```

```
! Second option: like normal, but add the native keyword
interface gigabitethernet 0/0.10
encapsulation dot1q 10 native
ip address 10.1.10.1 255.255.255.0
!
interface gigabitethernet 0/0.20
encapsulation dot1q 20
ip address 10.1.20.1 255.255.255.0
```

Besides just scanning the configuration, the **show vlans** command on a router spells out which router trunk interfaces use which VLANs, which VLAN is the native VLAN, plus some packet statistics. Example 16-4 shows a sample, based on the Router B1 configuration in Example 16-3 (bottom half), in which native VLAN 10 is configured on subinterface G0/0.10. Note that the output identifies VLAN 1 associated with the physical interface, VLAN 10 as the native VLAN associated with G0/0.10, and VLAN 20 associated with G0/0.20.

Example 16-4. Sample show vlans **Command to Match Sample Router Trunking Configuration**

Click here to view code image

```
R1# show vlans

Virtual LAN ID: 1 (IEEE 802.1Q Encapsulation)

vLAN Trunk Interface: GigabitEthernet0/0

Protocols Configured: Address: Received: Transmitted:
Other 0 83
```

```
69 packets, 20914 bytes input
147 packets, 11841 bytes output

Virtual LAN ID: 10 (IEEE 802.1Q Encapsulation)

vLAN Trunk Interface: GigabitEthernet0/0.10

This is configured as native Vlan for the following interface(s) :
GigabitEthernet0/0

Protocols Configured: Address: Received: Transmitted:
IP 10.1.10.1 2 3
Other 0 1

3 packets, 722 bytes input
4 packets, 264 bytes output

Virtual LAN ID: 20 (IEEE 802.1Q Encapsulation)

vLAN Trunk Interface: GigabitEthernet0/0.20

Protocols Configured: Address: Received: Transmitted:
IP 10.1.20.1 0 134
Other 0 1

0 packets, 0 bytes input
135 packets, 10498 bytes output
```

Finally, for those of you paying close attention to the exam topics, note that the subtopics about interVLAN routing and ROAS mention "upstream routing." This topic refers to a basic concept: The router that uses ROAS might only need to route between those subnets off the VLAN trunk, but more than likely, the router will also need to route packets to other subnets in other parts of the enterprise network. This "upstream routing" topic simply reminds us to not forget about the need to configure other router interfaces, static routes, a routing protocol, and so on, so that the router can forward packets to other "upstream" destinations.

Configuring Routing to VLANs Using a Layer 3 Switch

The other option for routing traffic to VLANs uses a device called a Layer 3 switch or multilayer switch. As introduced back in Chapter 9, "Implementing Ethernet Virtual LANs," a Layer 3 switch is one device that does two primary functions: Layer 2 LAN switching and Layer 3 IP routing. The Layer 2 switch function forwards frames inside each VLAN, but it will not forward frames between VLANs. The Layer 3 forwarding logic—routing—forwards IP packets between VLANs.

The configuration of a Layer 3 switch mostly looks like the Layer 2 switching configuration shown back in Part II of this book, with a small bit of configuration added for the Layer 3 functions. The Layer 3 switching function needs a virtual interface connected to each VLAN internal to the switch. These *VLAN interfaces* act like router interfaces, with an IP address and mask. The Layer 3 switch has an IP routing table, with connected routes off each of these VLAN interfaces. (These interfaces are also referred to as Switched Virtual Interfaces [SVI].)

To show the concept, Figure 16-13 shows the design changes and configuration concept for the same branch office used in Figures 16-11 and 16-12. The figure shows the Layer 3 switch function with a router icon inside the switch, to emphasize that the switch routes the packets. The branch still has two user VLANs, so the Layer 3 switch needs one VLAN interface for each VLAN. Additionally, the traffic still needs to get to the router to access the WAN, so the switch uses a third VLAN (VLAN 30 in this case) for the link to Router B1. This link would not be a trunk, but would be an access link.

Key Topic

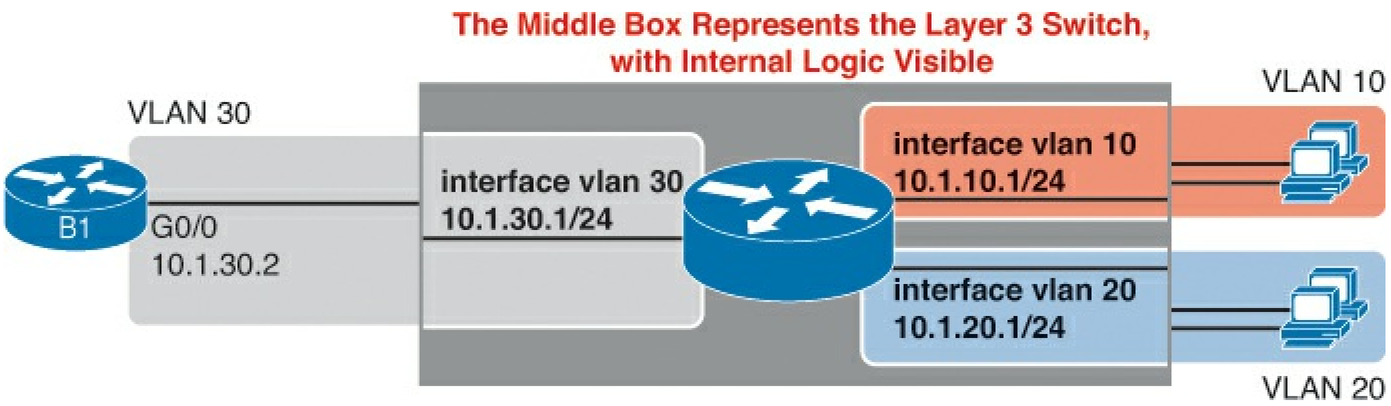


Figure 16-13. Routing on VLAN Interfaces in a Layer 3 Switch

The following steps show how to configure Layer 3 switching. Note that on some switches, like the 2960 switches used for the examples in this book, the ability to route IPv4 packets must be enabled first, with a **reload** of the switch required to enable the feature. The rest of the steps after Step 1 would apply to all models of Cisco switches that are capable of doing Layer 3 switching.

Key Topic

Step 1. Enable hardware support for IPv4 routing. For example, on 2960 switches, configure the **sdm prefer lanbase-routing** global command and **reload** the switch.

Step 2. Enable IPv4 routing globally (**ip routing**).

Step 3. Create VLAN interfaces for each VLAN for which the Layer 3 switch is routing packets (**interface vlan** *vlan_id*).

Step 4. Configure an IP address and mask on the VLAN interface (in interface configuration mode for that interface), enabling IPv4 on that VLAN interface (**ip address** *address mask*).

Step 5. If the switch defaults to place the VLAN interface in a disabled (shutdown) state, enable the interface (**no shutdown**).

Example 16-5 shows the configuration to match Figure 16-13. In this case, switch SW1, a 2960, has already used the **sdm prefer lanbase-routing** global command and been reloaded. The example shows the related configuration on all three VLAN interfaces.

Example 16-5. VLAN Interface Configuration for Layer 3 Switching

Click here to view code image

```
ip routing
!
interface vlan 10
ip address 10.1.10.1 255.255.255.0
!
interface vlan 20
ip address 10.1.20.1 255.255.255.0
!
interface vlan 30
ip address 10.1.30.1 255.255.255.0
```

With the VLAN configuration shown here, the switch is ready to route packets between the VLANs as shown in Figure 16-13. To support the routing of packets, the switch adds connected IP routes, as shown in Example 16-6; note that each route is listed as being connected to a different VLAN interface.

Example 16-6. Connected Routes on a Layer 3 Switch

Click here to view code image

```
SW1# show ip route
! legend omitted for brevity

10.0.0.0/8 is variably subnetted, 6 subnets, 2 masks
C 10.1.10.0/24 is directly connected, Vlan10
L 10.1.10.1/32 is directly connected, Vlan10
C 10.1.20.0/24 is directly connected, Vlan20
```

```
L 10.1.20.1/32 is directly connected, Vlan20
C 10.1.30.0/24 is directly connected, Vlan30
L 10.1.30.1/32 is directly connected, Vlan30
```

The switch would also need additional routes to the rest of the network shown in Figure 16-11, possibly using static routes as discussed in the final major section of this chapter.

Secondary IP Addressing

Most networks today make use of either routers with VLAN trunks or Layer 3 switches. This next topic moves to an interesting, but frankly less commonly used, feature that helps overcome some growing pains with an IP network.

Imagine that you planned your IP addressing scheme for a network. Later, a particular subnet grows, and you have used all the valid IP addresses in the subnet. What should you do? Three main options exist:

- Make the existing subnet larger, by choosing a mask with more host bits. Existing hosts have to change their subnet mask settings, and new hosts can use IP addresses from the expanded address range.
- Migrate to a completely new (larger) subnet. All existing devices change their IP addresses.
- Add a second subnet in the same location, using secondary addressing.

The first options works well, as long as the new subnet does not overlap with existing subnets. For example, if the design used 172.16.2.0/24, and it ran out of addresses, the engineer could try to use mask *23 instead. That creates a subnet 172.16.2.0*23, with a range of addresses from 172.16.2.1 to 172.16.3.254. However, if subnet 172.16.3.0/24 had already been assigned to some other part of the network, space would not exist in the addressing plan to make the existing subnet larger.

The second option is more likely to work. The engineer looks at the unused IP addresses in that IP network and picks a new subnet. However, all the existing IP addresses would need to be changed. This is a relatively simple process if most or all hosts use DHCP, but potentially laborious if many hosts use statically configured IP addresses.

The third option uses a Cisco router feature called *secondary IP addressing*. Secondary addressing uses multiple networks or subnets on the same data link. (This feature actually breaks the subnetting rules discussed earlier in this book, but it works.) By using more than one subnet in the same Layer 2 broadcast domain, you increase the number of available IP addresses.

Figure 16-14 shows the ideas behind secondary addressing. Hosts A and B sit on the same LAN, in fact, in the same VLAN. So does R1. No trunking needs to occur, either. In fact, if you ignore the numbers, normally, A, B, and R1 would all be part of the same subnet.

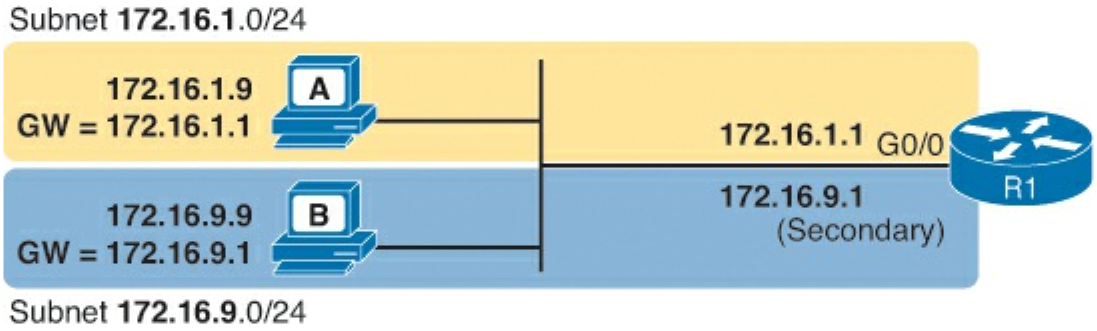


Figure 16-14. TCP/IP Network with Secondary Addresses

Secondary addressing allows some hosts to have addresses in one IP subnet, others to have addresses in a second IP subnet, and the router to have addresses in both. Both IP subnets would be in the same Layer 2 broadcast domain (VLAN). As a result, the router will have connected routes for both the subnets, so the router can route packets to both subnets and even between both subnets.

Example 16-7 shows the configuration on R1 to match the example shown in Figure 16-14. Note that the second **ip address** command must have the **secondary** keyword, implementing secondary addressing, which tells router to add this as an additional IP address. Without this keyword, the router would replace the other IP address.

Example 16-7. Secondary IP Addressing Configuration and the show ip route **Command**

Click here to view code image

```
! Excerpt from show running-config follows...
interface gigabitethernet 0/0
ip address 172.16.9.1 255.255.255.0 secondary
ip address 172.16.1.1 255.255.255.0

R1# show ip route connected
! lines omitted for brevity
172.16.0.0/16 is variably subnetted, 8 subnets, 2 masks
C 172.16.1.0/24 is directly connected, GigabitEthernet0/0
```

```
L 172.16.1.1/32 is directly connected, GigabitEthernet0/0
C 172.16.9.0/24 is directly connected, GigabitEthernet0/0
L 172.16.9.1/32 is directly connected, GigabitEthernet0/0
```

Secondary addressing does have one negative: Traffic between hosts on the same VLAN, but in different subnets, requires a trip through the router. For example, in Figure 16-14, when host A in subnet 172.16.1.0 sends a packet to host B, in subnet 172.16.9.0, host A's logic is to send the packet to its default gateway. So, the sending host sends the packet to the router, which then sends the packet to host B, which is in the other IP subnet but in the same Layer 2 VLAN.

Supporting Connected Routes to Subnet Zero

The other features discussed in this section—configuring IP addresses on physical interfaces, using ROAS, Layer 3 switching, and even secondary addressing—all give network engineers some options for how to connect routers to local subnets so that the router can route packets to and from those subnets. This last topic in the second major section of the chapter looks at a router feature that has been around for a long time to overcome some early problems in the history of IPv4, but today, you would not seek to use this feature as a means to an end.

IOS can restrict a router from configuring an **ip address** command with an address inside the zero subnet. The *zero subnet* (or *subnet zero*) is the one subnet in each classful network that has all binary 0s in the subnet part of the binary version of the subnet number. In decimal, the zero subnet happens to be the same number as the classful network number.

> **Note**
>
> Chapter 19, "Subnet Design," discusses the concept around zero subnets in a little more detail.

IOS allows the network engineer to tell a router to either allow addresses in the zero subnet or not. The motivation has to do with some older IP routing protocols that did not support the use of the zero subnet. Basically, with the **ip subnet-zero** command configured, IOS allows the zero subnet with no restrictions. With the **no ip subnet-zero** command configured, the router rejects any **ip address** command that uses an address/mask combination for the zero subnet. For many of the more recent IOS versions, IOS allows the use of the zero subnet.

Example 16-8 shows how a router accepts the interface subcommand **ip address 10.0.0.1 255.255.255.0** at first, with the default setting, but later rejects the command after changing to use **no ip subnet-zero**. Note that the error message does not mention the zero subnet, instead simply stating "bad mask."

Example 16-8. Effects of [no] ip subnet-zero **on a Local Router**

Click here to view code image

```
R1# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R1(config)# interface g0/1
R1(config-if)# ip address 10.0.0.1 255.255.255.0
R1(config-if)# no ip address
R1(config-if)# exit
R1(config)# no ip subnet-zero
R1(config)# interface g0/1
R1(config-if)# ip address 10.0.0.1 255.255.255.0
Bad mask /24 for address 10.0.0.1
```

Note that the **no ip subnet-zero** command affects the local router's **ip address** commands, as well as the local router's **ip route** commands (which define static routes). However, it does not affect the local router's routes as learned with a routing protocol. For example, R1 could be configured with **no ip subnet-zero**, but still learn a route for a zero subnet using a routing protocol.

Configuring Static Routes

All routers add connected routes, as discussed in the previous section. Then, most networks use dynamic routing protocols to cause each router to learn the rest of the routes in an internetwork. Networks use static routes—routes added to a routing table through direct configuration—much less often than dynamic routing. However, static routes can be useful at times, and they happen to be useful learning tools as well. This last of three major sections in the chapter discusses static routes.

Static Route Configuration

IOS allows the definition of individual static routes using the **ip route** global configuration command. Every **ip route** command defines a destination that can be matched, usually with a subnet ID and mask. The command also lists the forwarding instructions, typically listing either the outgoing interface or the next-hop router's IP address. IOS then takes that information and adds that route to the IP routing table.

As an example, Figure 16-15 shows a small IP network. The diagram actually holds a subset of Figure 16-3, from earlier in this chapter, with some of the unrelated details removed. The figure shows only the details related to a static route on R1, for subnet 172.16.2.0/24, which sits on the far right. To create that static route on R1, R1 will configure the subnet ID and mask, and either R1's outgoing interface (S0/0/0), or R2 as the next-hop router IP address (172.16.4.2).

Key Topic

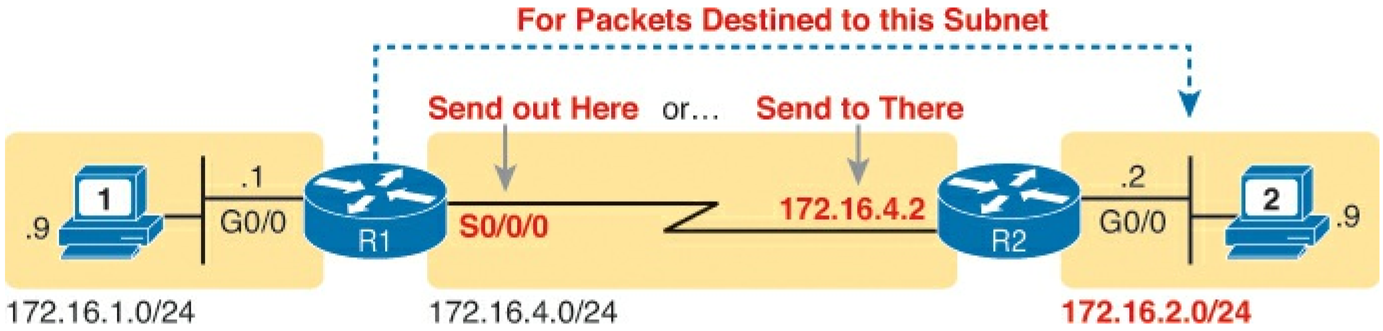

For Packets Destined to this Subnet
Send out Here
or...
Send to There
1
.9
.1
G0/0
R1
S0/0/0
172.16.4.2
R2
.2
G0/0
2
.9
172.16.1.0/24
172.16.4.0/24
172.16.2.0/24

Figure 16-15. Static Route Configuration Concept

Example 16-9 shows the configuration of a couple of sample static routes. In particular, it shows routes on Router R1 in Figure 16-16, for the two subnets on the right side of the figure.

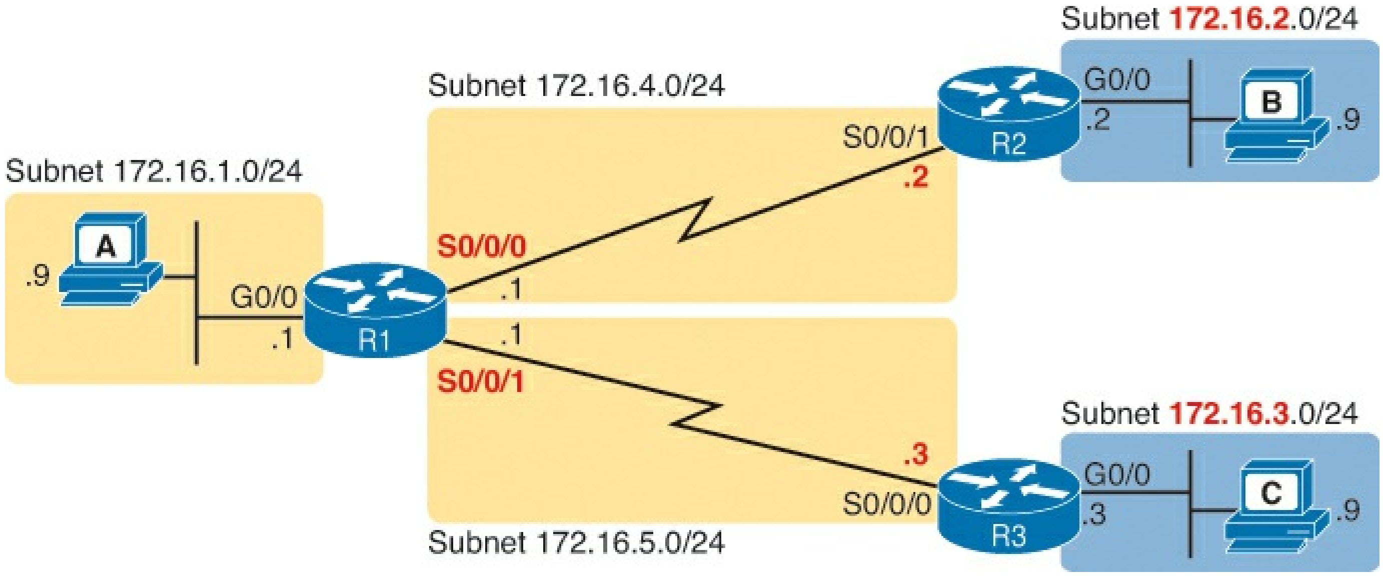

Subnet 172.16.2.0/24
Subnet 172.16.4.0/24
Subnet 172.16.1.0/24
A
.9
G0/0
.1
R1
S0/0/0
.1
.1
S0/0/1
S0/0/1
.2
R2
G0/0
.2
B
.9
.3
S0/0/0
R3
G0/0
.3
C
.9
Subnet 172.16.3.0/24
Subnet 172.16.5.0/24

Figure 16-16. Sample Network Used in Static Route Configuration Examples

Example 16-9. Static Routes Added to R1

Click here to view code image

```
ip route 172.16.2.0 255.255.255.0 172.16.4.2
ip route 172.16.3.0 255.255.255.0 S0/0/1
```

The two example **ip route** commands show the two different styles. The first command shows subnet 172.16.2.0, mask 255.255.255.0, which sits on a LAN near Router R2. That same first command lists 172.16.4.2, R2's IP address, as the next-hop router. This route basically says this: To send packets to the subnet off Router R2, send them to R2.

The second route has the same kind of logic, but instead of identifying the next router by IP address, it lists the local router's outgoing interface. This route basically states: To send packets to the subnet off Router R3, send them out my own local S0/0/1 interface (which happens to connect to R3).

The routes created by these two **ip route** commands actually look a little different in the IP routing table. Both are static routes. However, the route that used the outgoing interface configuration is also noted as a connected route; this is just a quirk of the output of the **show ip route** command.

Example 16-10 lists these two routes using the **show ip route static** command. This command lists the details of static routes only, but it also lists a few statistics about all IPv4 routes. For example, the example shows two lines, for the two static routes configured in Example 16-9, but statistics state that this routes has routes for ten subnets.

Example 16-10. Static Routes Added to R1

Click here to view code image

```
R1# show ip route static
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
! lines omitted for brevity
Gateway of last resort is not set

172.16.0.0/16 is variably subnetted, 10 subnets, 2 masks
S 172.16.2.0/24 [1/0] via 172.16.4.2
S 172.16.3.0/24 is directly connected, Serial0/0/1
```

IOS adds and removes these static routes dynamically over time, based on whether the outgoing interface is working or not. For example, in this case, if R1's S0/0/1 interface fails, R1 removes the static route to 172.16.3.0/24 from the IPv4 routing table. Later, when the interface comes up again, IOS adds the route back to the routing table. Also, note that the **ip route** command also supports the **permanent** keyword, which tells IOS to leave the static route in the routing table, even when the associated interface fails.

Finally, if using static routes, and not using any dynamic routing protocols at all, all routers would need to have some static routes configured. For example, at this point, in the network if Figure 16-16, PC A would not be able to receive packets back from PC B, because Router R2 does not have a route for PC A's subnet. R2 would need static routes for other subnets, as would R3.

Static Default Routes

When a router tries to route a packet, the router might not match the packet's destination IP address with any route. When that happens, the router normally just discards the packet.

Routers can be configured so that they use either a statically configured or dynamically learned default route. The default route matches all packets, so that if a packet does not match any other more specific route in the routing table, the router can at least forward the packet based on the default route.

One classic example in which companies might use static default routes in their enterprise TCP/IP networks is when the company has many remote sites, each with a single, relatively slow WAN connection. Each remote site has only one possible physical route to use to send packets to the rest of the network. So, rather than use a routing protocol, which sends messages over the WAN and uses precious WAN bandwidth, each remote route might use a default route that sends all traffic to the central site, as shown in Figure 16-17.

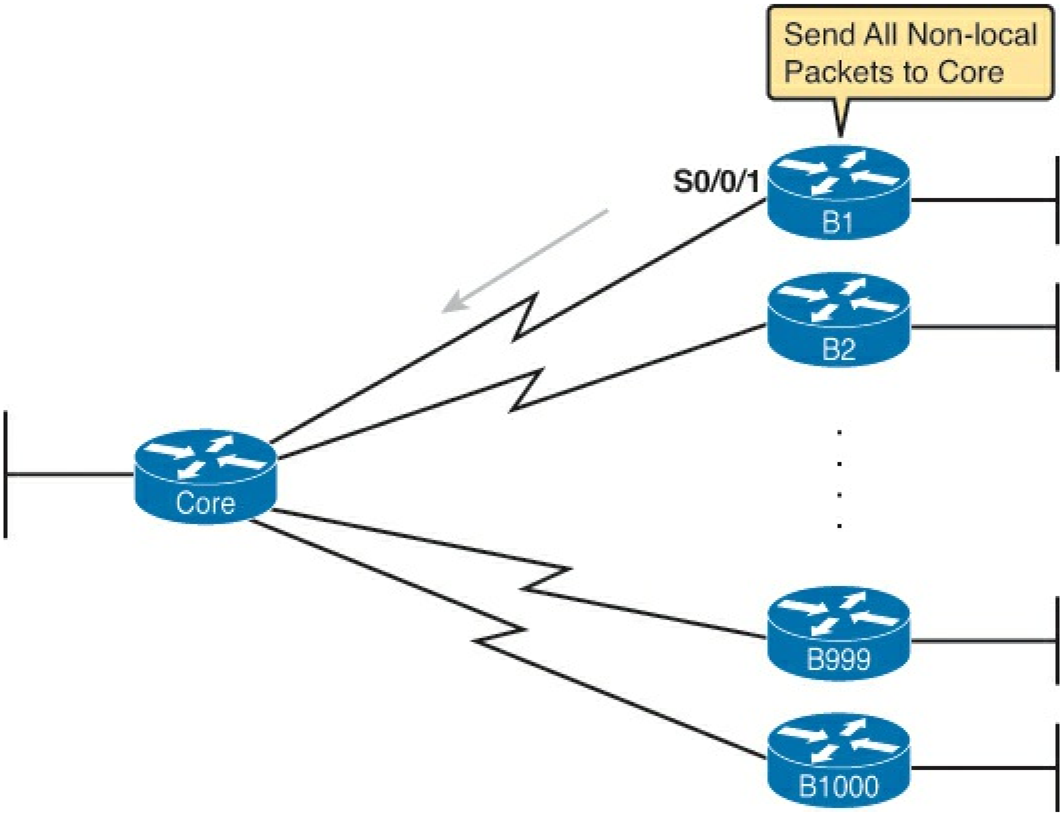


Figure 16-17. Example Use of Static Default Routes at 1000 Low-Speed Remote Sites

IOS allows the configuration of a static default route by using special values for the subnet and mask fields in the **ip route** command: 0.0.0.0 and 0.0.0.0. For example, the command **ip route 0.0.0.0 0.0.0.0 S0/0/1** creates a static default route on Router B1—a route that matches all IP packets—and sends those packets out interface S0/0/1.

Example 16-11 shows an example of a static default route, using Router R2 from recent Figure 16-16. Earlier, that figure, along with example 16-9, showed R1 with static routes to the two subnets on the right side of the figure. Example 16-11 shows R2, on the right, using a static default route to route packets back to the left side of the figure.

Example 16-11. Adding a Static Default Route on R2 (Figure 16-16)

Click here to view code image

```
R2# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R2(config)# ip route 0.0.0.0 0.0.0.0 s0/0/1
R2(config)# ^Z
R2# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
E1 - OSPF external type 1, E2 - OSPF external type 2
i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
ia - IS-IS inter area, * - candidate default, U - per-user static route
o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
+ - replicated route, % - next hop override

Gateway of last resort is 0.0.0.0 to network 0.0.0.0

S* 0.0.0.0/0 is directly connected, Serial0/0/1
172.16.0.0/16 is variably subnetted, 4 subnets, 2 masks
C 172.16.2.0/24 is directly connected, GigabitEthernet0/0
L 172.16.2.2/32 is directly connected, GigabitEthernet0/0
C 172.16.4.0/24 is directly connected, Serial0/0/1
L 172.16.4.2/32 is directly connected, Serial0/0/1
```

The output of the **show ip route** command lists a few new and interesting facts. First, it lists the route with a code of "S," meaning static, but also with a *, meaning it is a *candidate default route*. A router can learn about more than one default route, and the router then has to choose which one to use; the * means that it is at least a candidate to become the default route. Just above, the "Gateway of Last Resort" refers to the chosen default route, which in this case is the just-configured static route with outgoing interface S0/0/1.

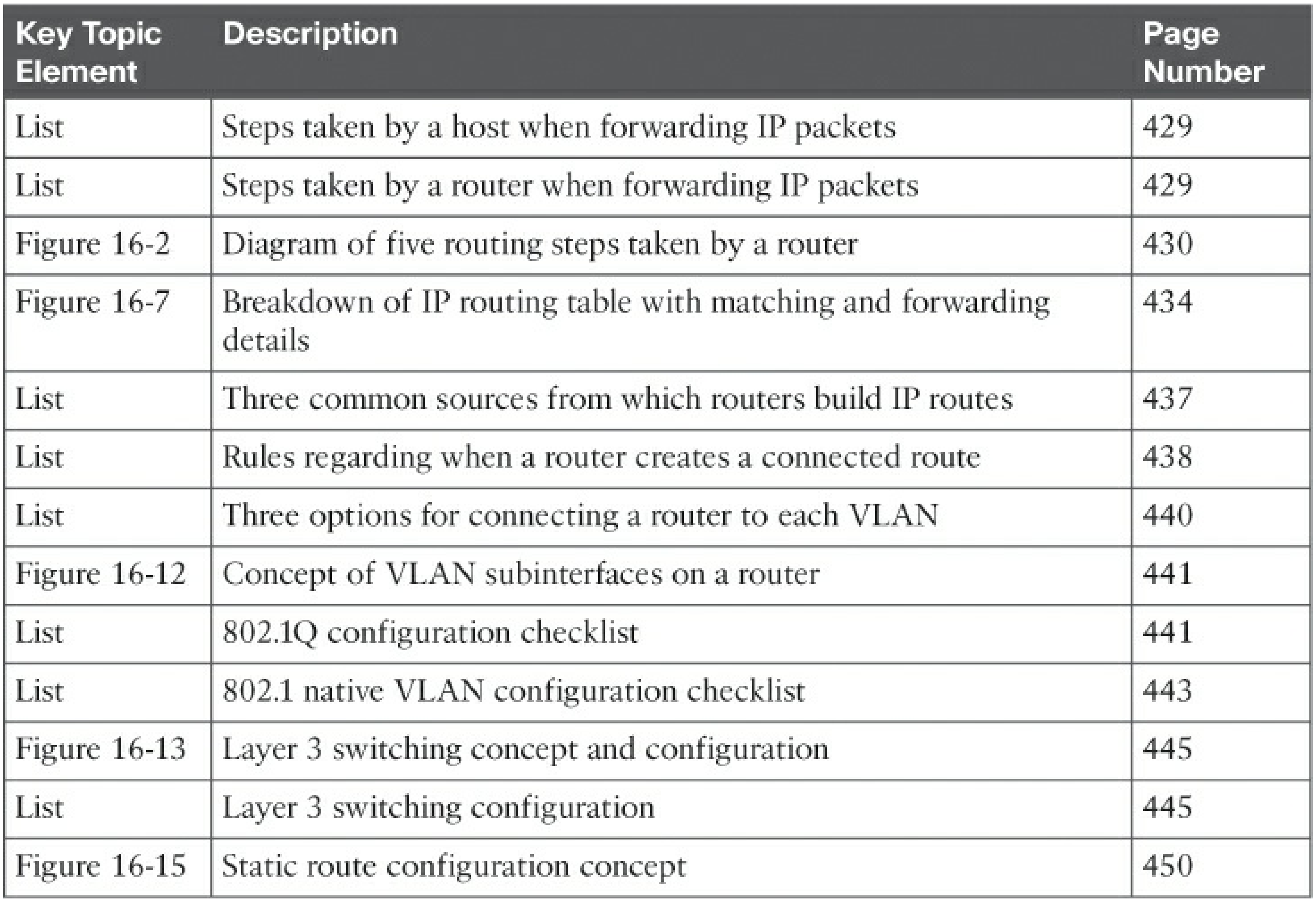
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 16-3 lists these key topics and where each is discussed.

Key Topic

Table 16-3. Key Topics for Chapter 16



Key Topic Element	Description	Page Number
List	Steps taken by a host when forwarding IP packets	429
List	Steps taken by a router when forwarding IP packets	429
Figure 16-2	Diagram of five routing steps taken by a router	430
Figure 16-7	Breakdown of IP routing table with matching and forwarding details	434
List	Three common sources from which routers build IP routes	437
List	Rules regarding when a router creates a connected route	438
List	Three options for connecting a router to each VLAN	440
Figure 16-12	Concept of VLAN subinterfaces on a router	441
List	802.1Q configuration checklist	441
List	802.1 native VLAN configuration checklist	443
Figure 16-13	Layer 3 switching concept and configuration	445
List	Layer 3 switching configuration	445
Figure 16-15	Static route configuration concept	450

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists for you to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

default gateway/router
ARP table
routing table
next-hop router
outgoing interface
subinterface
VLAN interface
Layer 3 switch
Cisco Express Forwarding (CEF)
connected route
static route
default route
zero subnet

Command Reference to Check Your Memory

Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To check to see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table with a piece of paper, read the descriptions on the right side, and see whether you remember the command.

Table 16-4. Chapter 16 Configuration Command Reference

Command	Description
ip address *ip-address mask* [**secondary**]	Interface subcommand that assigns the interface's IP address and optionally makes the address a secondary address
interface *type number.subint*	Global command to create a subinterface and to enter configuration mode for that subinterface
encapsulation dot1q *vlan-id* [**native**]	A subinterface subcommand that tells the router to use 802.1Q trunking, for a particular VLAN, and with the **native** keyword, to not encapsulate in a trunking header
encapsulation isl *vlan-identifier*	A subinterface subcommand that tells the router to use ISL trunking for a particular VLAN
sdm prefer lanbase-routing	A command on Cisco switches that enables the switch to support IP routing if configured
[**no**] **ip routing**	Global command that enables (**ip routing**) or disables (**no ip routing**) the routing of IPv4 packets on a router or Layer 3 switch
interface vlan *vlan_id*	Global command on a Layer 3 switch to create a VLAN interface and to enter configuration mode for that VLAN interface
[**no**] **ip subnet-zero**	Global command that allows (**ip subnet-zero**) or disallows (**no ip subnet-zero**) the configuration of an interface IP address in a zero subnet
ip route *prefix mask* {*ip-address* | *interface-type interface-number*} [*distance*] [**permanent**]	Global configuration command that creates a static route
ip default-network *network-number*	Global command that creates a default route based on the router's route to reach the classful network listed in the command

Table 16-5. Chapter 16 EXEC Command Reference

Command	Description
show ip route	Lists the router's entire routing table
show ip route [**connected** | **static** | **ospf**]	Lists a subnet of the IP routing table
show ip route *ip-address*	Lists detailed information about the route that a router matches for the listed IP address
show vlans	Lists VLAN configuration and statistics for VLAN trunks configured on routers

Chapter 17. Learning IPv4 Routes with OSPFv2

This chapter covers the following exam topics:

IP Routing Technologies

- Configure and verify utilizing the CLI to set basic Router configuration
  - Cisco IOS commands to perform basic router setup
- Verify router configuration and network connectivity
  - Cisco IOS commands to review basic router information and network connectivity
- Differentiate methods of routing and routing protocols
  - Static vs. Dynamic
  - Link state vs. Distance Vector
  - Passive interfaces
- Configure and verify OSPF (single area)
  - Benefit of single area
  - Configure OSPF v2
  - Router ID
  - Passive interface

The Open Shortest Path First (OSPF) routing protocol can be used by each router such that all routers learn routes to all subnets in an enterprise IPv4 network. In fact, with a relatively simple OSPF design, the routers could all use the same exact OSPF configuration, with two commands: **router ospf 1** and **network 0.0.0.0 255.255.255.255 area 0**. If your only goal was to get OSPF working right now, ignoring any desire to understand it, you could just skip the chapter, configure all the routers, and be finished. (Tempting, isn't it?)

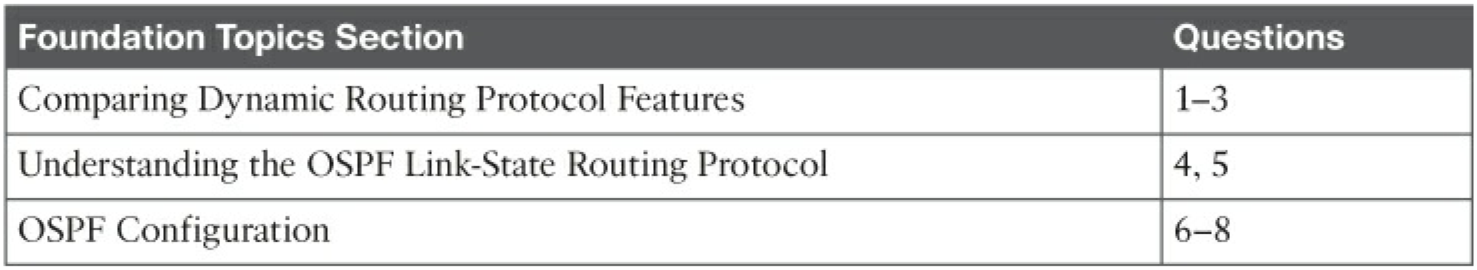
Of course, both for real networking jobs and for the CCENT and CCNA exams, it helps to both understand the concepts and to know the configuration options. This chapter walks you through the entire process, all in one chapter. It starts with a major section that compares different routing protocols, and different concepts related to routing protocols, to introduce the topic. The middle of the three major sections looks at the theory behind link-state routing protocols, because OSPF uses link-state principles. The last section shows how to configure OSPF using basic parameters, with the corresponding **show** commands.

Note that OSPF version 2 (OSPFv2) happens to be the long-established version of OSPF used for IPv4, while OSPF version 3 (OSPFv3) was defined specifically to support IPv6. So, this chapter discusses routing protocols for IPv4 only, so all references to OSPF refer to OSPFv2. Chapter 29, "Implementing IPv6 Routing," discusses OSPF's use with IPv6.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 17-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Comparing Dynamic Routing Protocol Features	1–3
Understanding the OSPF Link-State Routing Protocol	4, 5
OSPF Configuration	6–8

1. Which of the following routing protocols are considered to use link-state logic? (Choose two answers.)
   - **a.** RIP-1
   - **b.** RIP-2
   - **c.** EIGRP
   - **d.** OSPF
   - **e.** Integrated IS-IS
2. Which of the following routing protocols use a metric that is, by default, at least partially affected by link bandwidth? (Choose two answers.)
   - **a.** RIP-1
   - **b.** RIP-2
   - **c.** EIGRP

d. OSPF

3. Which of the following interior routing protocols support VLSM? (Choose four answers.)

a. RIP-1

b. RIP-2

c. EIGRP

d. OSPF

e. Integrated IS-IS

4. Which of the following is true about how a router using a link-state routing protocol chooses the best route to reach a subnet?

a. The router finds the best route in the link-state database.

b. The router calculates the best route by running the SPF algorithm against the information in the link-state database.

c. The router compares the metrics listed for that subnet in the updates received from each neighbor and picks the best (lowest) metric route.

d. The router uses the path that has the lowest hop count.

5. OSPF runs an algorithm to calculate the currently best route. Which of the following terms refer to that algorithm? (Choose two answers.)

a. SPF

b. DUAL

c. Feasible successor

d. Dijkstra

e. Good old common sense

6. Which of the following **network** commands, following the command **router ospf 1**, tells this router to start using OSPF on interfaces whose IP addresses are 10.1.1.1, 10.1.100.1, and 10.1.120.1?

a. network 10.0.0.0 255.0.0.0 area 0

b. network 10.0.0.0 0.255.255.255 area 0

c. network 10.0.0.1 0.0.0.255 area 0

d. network 10.0.0.1 0.0.255.255 area 0

7. Which of the following **network** commands, following the command **router ospf 1**, tells this router to start using OSPF on interfaces whose IP addresses are 10.1.1.1, 10.1.100.1, and 10.1.120.1?

a. network 0.0.0.0 255.255.255.255 area 0

b. network 10.0.0.0 0.255.255.0 area 0

c. network 10.1.1.0 0.x.1x.0 area 0

d. network 10.1.1.0 255.0.0.0 area 0

e. network 10.0.0.0 255.0.0.0 area 0

8. Which of the following commands list the OSPF neighbors off interface serial 0/0? (Choose two answers.)

a. show ip ospf neighbor

b. show ip ospf interface brief

c. show ip neighbor

d. show ip interface

e. show ip ospf neighbor serial 0/0

Answers to the "Do I Know This Already?" quiz:

1 D and E **2** C and D **3** B, C, D, and E **4** B **5** A and D **6** B **7** A **8** A and E

Foundation Topics

Comparing Dynamic Routing Protocol Features

Routers add IP routes to their routing tables using three methods: connected routes, static routes, and routes learned by using dynamic routing protocols. Before we get too far into the discussion, however, it is important to define a few related terms and clear up any misconceptions about the terms *routing protocol*, *routed protocol*, and *routable protocol*. The concepts behind these terms are not that difficult, but because the terms are so similar, and because many documents pay poor attention to when each of these terms is used, they can be a bit confusing. These terms are generally defined as follows:

- **Routing protocol:** A set of messages, rules, and algorithms used by routers for the overall purpose of learning routes. This process includes the exchange and analysis of routing information. Each router chooses the best route to each subnet (path selection) and finally places those best routes in its IP routing table. Examples include RIP, EIGRP, OSPF, and BGP.
- **Routed protocol and routable protocol:** Both terms refer to a protocol that defines a packet structure and logical addressing, allowing routers to forward or route the packets. Routers forward packets defined by routed and routable protocols. Examples include IP Version 4 (IPv4) and IP Version 6 (IPv6).

> **Note**
>
> The term *path selection* sometimes refers to part of the job of a routing protocol, in which the routing protocol chooses the best route.

Even though routing protocols (such as OSPF) are different from routed protocols (such as IP), they do work together very closely. The routing process forwards IP packets, but if a router does not have any routes in its IP routing table that match a packet's destination address, the router discards the packet. Routers need routing protocols so that the routers can learn all the possible routes and add them to the routing table, so that the routing process can forward (route) routable protocols such as IP.

Routing Protocol Functions

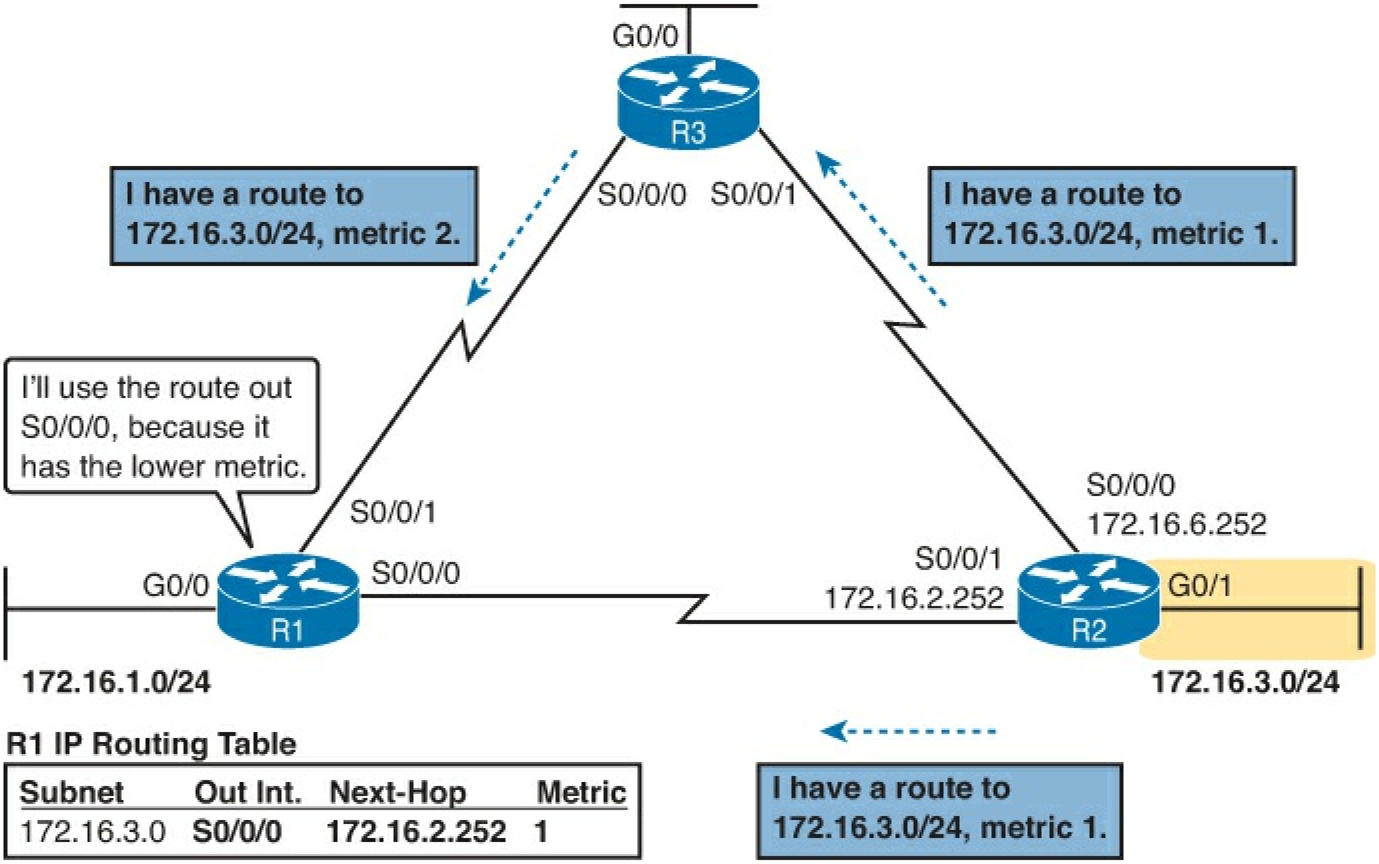
Cisco IOS software supports several IP routing protocols, performing the same general functions:

Key Topic

1. Learn routing information about IP subnets from other neighboring routers.
2. Advertise routing information about IP subnets to other neighboring routers.
3. If more than one possible route exists to reach one subnet, pick the best route based on a metric.
4. If the network topology changes—for example, a link fails—react by advertising that some routes have failed and pick a new currently best route. (This process is called convergence.)

> **Note**
>
> A neighboring router connects to the same link as another router, for example, the same WAN link or the same Ethernet LAN.

Figure 17-1 shows an example of three of the four functions in the list. Both R1 and R3 learn about a route to subnet 172.16.3.0/24 from R2 (function 1). After R3 learns about the route to 172.16.3.0/24 from R2, R3 advertises that route to R1 (function 2). Then R1 must make a decision about the two routes it learned about for reaching subnet 172.16.3.0/24: one with metric 1 from R2 and one with metric 2 from R3. R1 chooses the lower metric route through R2 (function 3).


G0/0
R3
S0/0/0 S0/0/1
I have a route to 172.16.3.0/24, metric 2.
I have a route to 172.16.3.0/24, metric 1.
I'll use the route out S0/0/0, because it has the lower metric.
S0/0/1
S0/0/0
172.16.6.252
G0/0
S0/0/0
R1
S0/0/1
172.16.2.252
R2
G0/1
172.16.1.0/24
172.16.3.0/24
R1 IP Routing Table
I have a route to 172.16.3.0/24, metric 1.

Subnet	Out Int.	Next-Hop	Metric
172.16.3.0	S0/0/0	172.16.2.252	1

Figure 17-1. Three of the Four Basic Functions of Routing Protocols

Convergence is the fourth routing protocol function listed here. The term *convergence* refers to a process that occurs when the topology changes—that is, when either a router or link fails or comes back up again. When something changes, the best routes available in the network can change. Convergence simply refers to the process by which all the routers collectively realize something has changed, advertise the information about the changes to all the other routers, and all the routers then choose the currently best routes for each subnet. The ability to converge quickly, without causing loops, is one of the most important considerations when choosing which IP routing protocol to use.

In Figure 17-1, convergence might occur if the link between R1 and R2 failed. In that case, R1 should stop using its old route for subnet 172.16.3.0/24 (directly through R2) and begin sending packets to R3.

Interior and Exterior Routing Protocols

IP routing protocols fall into one of two major categories: *interior gateway protocols (IGP)* or *exterior gateway protocols (EGP)*. The definitions of each are as follows:

Key Topic

- **IGP:** A routing protocol that was designed and intended for use inside a single autonomous system (AS)
- **EGP:** A routing protocol that was designed and intended for use between different autonomous systems

Note

The terms IGP and EGP include the word gateway because routers used to be called gateways.

These definitions use another new term: autonomous system (AS). An AS is a network under the administrative control of a single organization. For example, a network created and paid for by a single company is probably a single AS, and an network created by a single school system is probably a single AS. Other examples include large divisions of a state or national government, where different government agencies might be able to build their own networks. Each ISP is also typically a single different AS.

Some routing protocols work best inside a single AS by design, so these routing protocols are called IGPs. Conversely, routing protocols designed to exchange routes between routers in different autonomous systems are called EGPs. Today, Border Gateway Protocol (BGP) is the only EGP used.

Each AS can be assigned a number called (unsurprisingly) an *AS number (ASN)*. Like public IP addresses, the Internet Assigned Numbers Authority (IANA, www.iana.org) controls the worldwide rights to assigning ASNs. It delegates that authority to other organizations around the world, typically to the same organizations that assign public IP addresses. For example, in North America, the American Registry for Internet Numbers (ARIN, www.arin.net) assigns public IP address ranges and ASNs.

Figure 17-2 shows a small view of the worldwide Internet. The figure shows two enterprises and three ISPs using IGPs (OSPF and EIGRP) inside their own networks and with BGP being used between the ASNs.

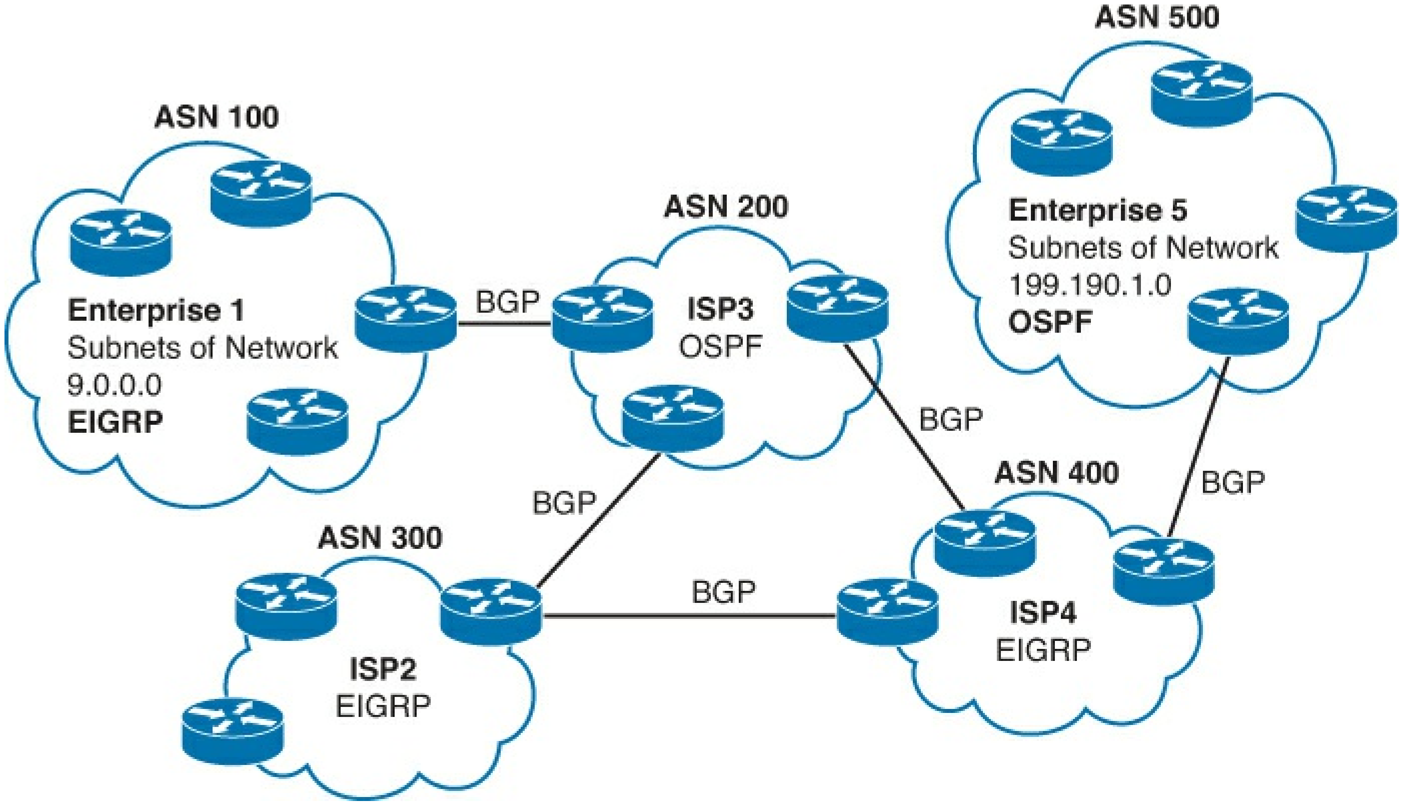


Figure 17-2. Comparing Locations for Using IGPs and EGPs

Comparing IGPs

Organizations have several options when choosing an IGP for their enterprise network, but most companies today use either OSPF or EIGRP. This book discusses OSPF in some depth, with the ICND2 book discussing more about OSPF and also introducing EIGRP. While these books will compare and contrast these most common IGPs, this section first discusses some of the main goals of every IGP, comparing OSPF, EIGRP, plus a few other IPv4 routing protocols.

IGP Routing Protocol Algorithms

A routing protocol's underlying algorithm determines how the routing protocol does its job. The term *routing protocol algorithm* simply refers to the logic and processes used by different routing protocols to solve the problem of learning all routes, choosing the best route to each subnet, and converging in reaction to changes in the internetwork. Three main branches of routing protocol algorithms exist for IGP routing protocols:

Key Topic

- Distance vector (sometimes called Bellman-Ford after its creators)
- Advanced distance vector (sometimes called "balanced hybrid")
- Link-state

Historically speaking, distance vector protocols were invented first, mainly in the early 1980s. Routing Information Protocol (RIP) was the first popularly used IP distance vector protocol, with the Cisco-proprietary Interior Gateway Routing Protocol (IGRP) being introduced a little later.

By the early 1990s, distance vector protocols' somewhat slow convergence and potential for routing loops drove the development of new alternative routing protocols that used new algorithms. Link-state protocols—in particular, Open Shortest Path First (OSPF) and Integrated Intermediate System to Intermediate System (IS-IS)—solved the main issues. They also came with a price: They required extra CPU and memory on routers, with more planning required from the network engineers.

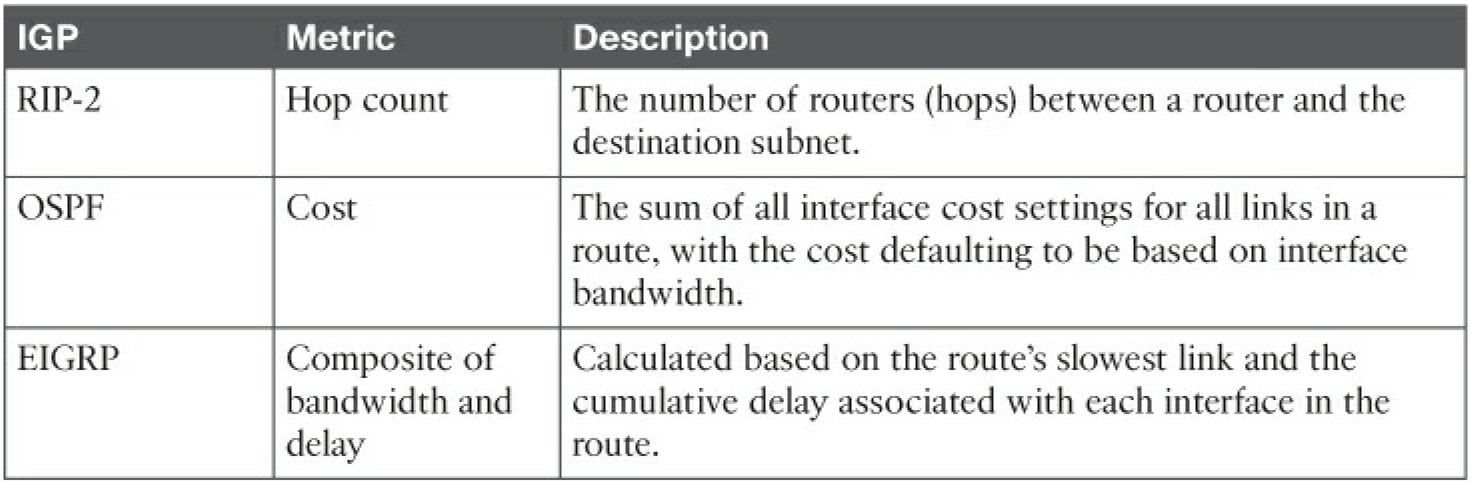
Around the same time as the introduction of OSPF, Cisco created a proprietary routing protocol called Enhanced Interior Gateway Routing Protocol (EIGRP), which used some features of the earlier IGRP protocol. EIGRP solved the same problems as did link-state routing protocols, but less planning was required when implementing the network. As time went on, EIGRP was classified as a unique type of routing protocol. However, it used more distance vector features than link-state, so it is more commonly classified as an advanced distance vector protocol.

Metrics

Routing protocols choose the best route to reach a subnet by choosing the route with the lowest metric. For example, RIP uses a counter of the number of routers (hops) between a router and the destination subnet. OSPF totals the cost associated with each interface in the end-to-end route, with the cost based on link bandwidth. Table 17-2 lists the most important IP routing protocols for the CCNA exams and some details about the metric in each case.

Key Topic

Table 17-2. IP IGP Metrics



IGP	Metric	Description
RIP-2	Hop count	The number of routers (hops) between a router and the destination subnet.
OSPF	Cost	The sum of all interface cost settings for all links in a route, with the cost defaulting to be based on interface bandwidth.
EIGRP	Composite of bandwidth and delay	Calculated based on the route's slowest link and the cumulative delay associated with each interface in the route.

While today's CCENT and CCNA R/S exams ignore RIP, a brief comparison of the metric used by the older RIP, versus the metric used by EIGRP, shows some insight into why OSPF and EIGRP surpassed RIP. Figure 17-3 shows an example in which Router B has two possible routes to subnet 10.1.1.0 on the left side of the network: a shorter route over a very slow 64-Kbps link, or a longer route over two higher-speed (T1) links.

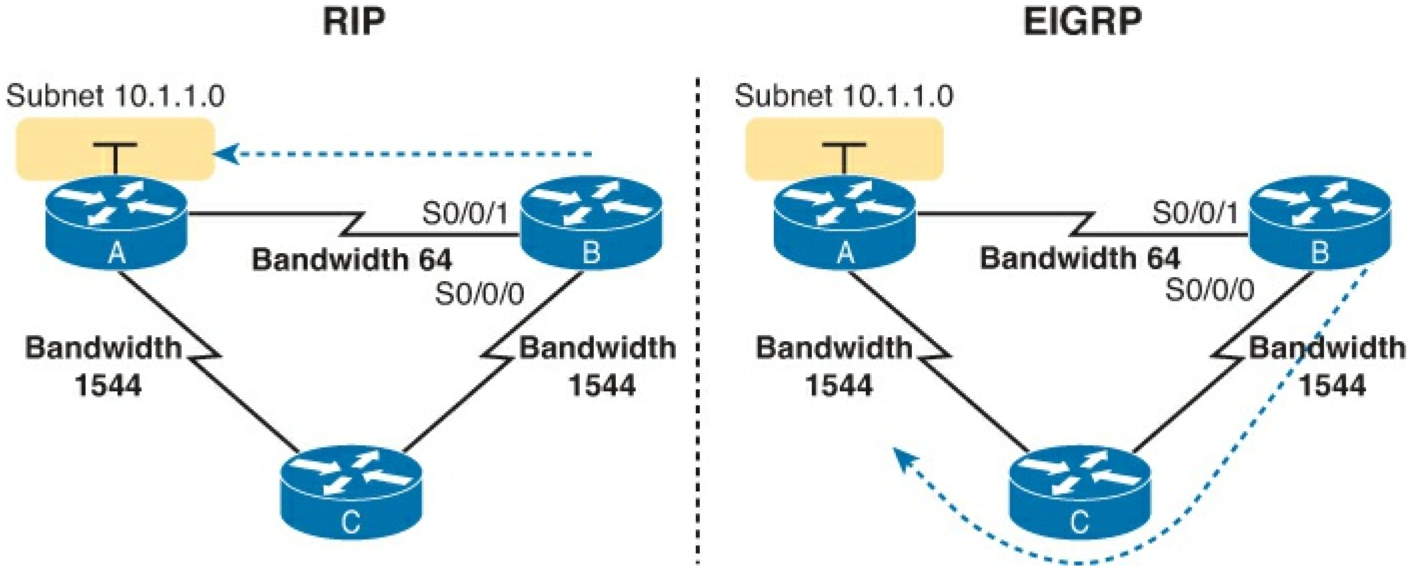


Figure 17-3. RIP and EIGRP Metrics Compared

The left side of the figure shows the results of RIP in this network. Using hop count, Router B learns of a 1-hop route directly to Router A through B's S0/0/1 interface. B also learns a two-hop route through Router C, through B's S0/0/0 interface. Router B chooses the lower hop count route, which happens to go over the slow speed link.

The right side of the figure shows the arguably better choice made by EIGRP based on its better metric.

To cause EIGRP to make the right choice, the engineer correctly configured the interface bandwidth to match the actual link speeds, thereby allowing EIGRP to choose the faster route. (The **bandwidth** interface subcommand does not change the actual physical speed of the interface. It just tells the IOS what speed to assume the interface is using.)

Other IGP Comparisons

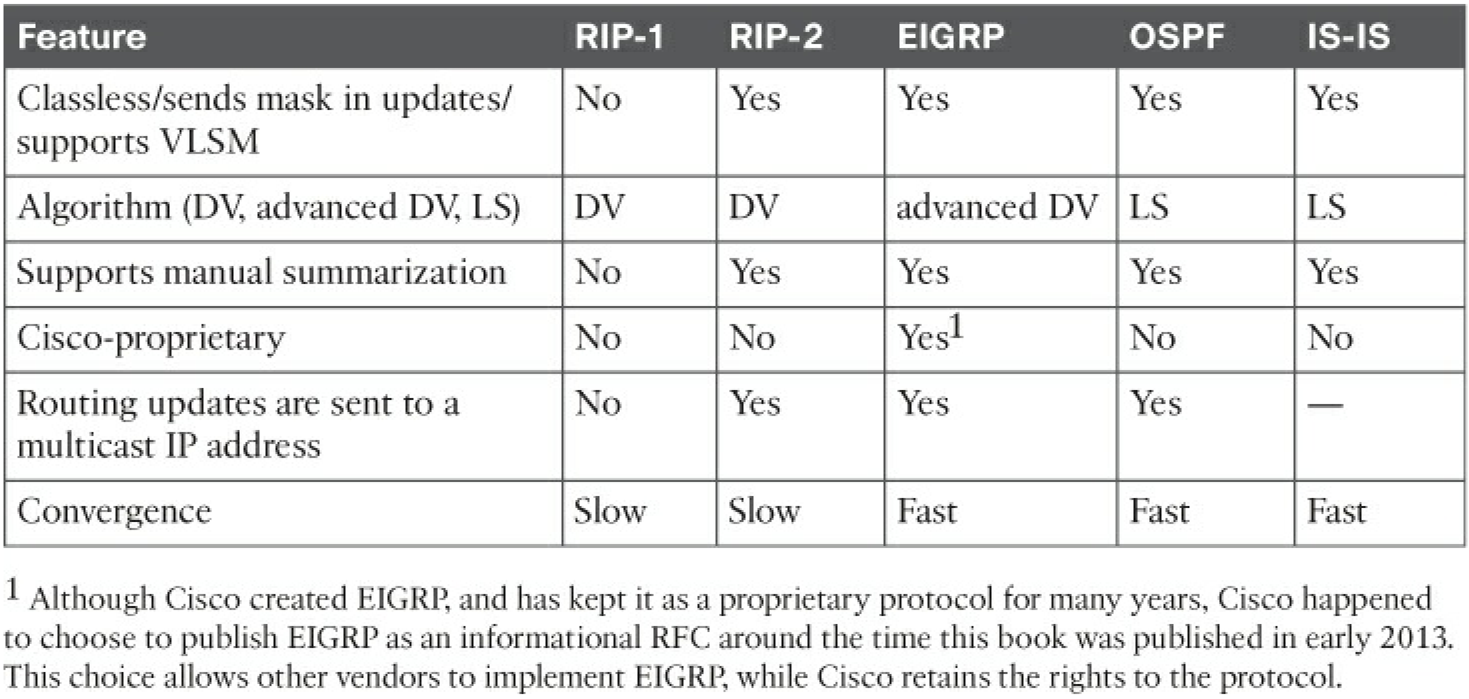
Some other IGP comparisons can be made. However, some topics require more fundamental knowledge of specific routing protocols, or other features not yet covered in this book. For now, this section introduces a few more comparison points, and leaves the details until later in the book.

First, routing protocols differ based on whether they are classless routing protocols (thereby supporting VLSM), or classful, which means they do not support VLSM. VLSM, as discussed at length in Chapter 20, "Variable Length Subnet Masks," is a subnetting design that uses more than one mask in different subnets of the same Class A, B, or C network. *Classless routing protocols* support VLSM by sending Updates with subnet masks in the message, whereas the generally older classful routing protocols do not send masks in the routing update messages.

Routing protocols also differ in how they support route summarization. Chapter 21, "Route Summarization," discusses these features in some depth, but for now, know that modern networks want to be able to use manual route summarization, and all the IGP routing protocols mentioned in this book, except the truly old RIP Version 1 (RIP-1), supports manual route summarization.

Table 17-3 summarizes the key IGP comparison points.

Table 17-3. Interior IP Routing Protocols Compared



Feature	RIP-1	RIP-2	EIGRP	OSPF	IS-IS
Classless/sends mask in updates/ supports VLSM	No	Yes	Yes	Yes	Yes
Algorithm (DV, advanced DV, LS)	DV	DV	advanced DV	LS	LS
Supports manual summarization	No	Yes	Yes	Yes	Yes
Cisco-proprietary	No	No	Yes[1]	No	No
Routing updates are sent to a multicast IP address	No	Yes	Yes	Yes	—
Convergence	Slow	Slow	Fast	Fast	Fast

[1] Although Cisco created EIGRP, and has kept it as a proprietary protocol for many years, Cisco happened to choose to publish EIGRP as an informational RFC around the time this book was published in early 2013. This choice allows other vendors to implement EIGRP, while Cisco retains the rights to the protocol.

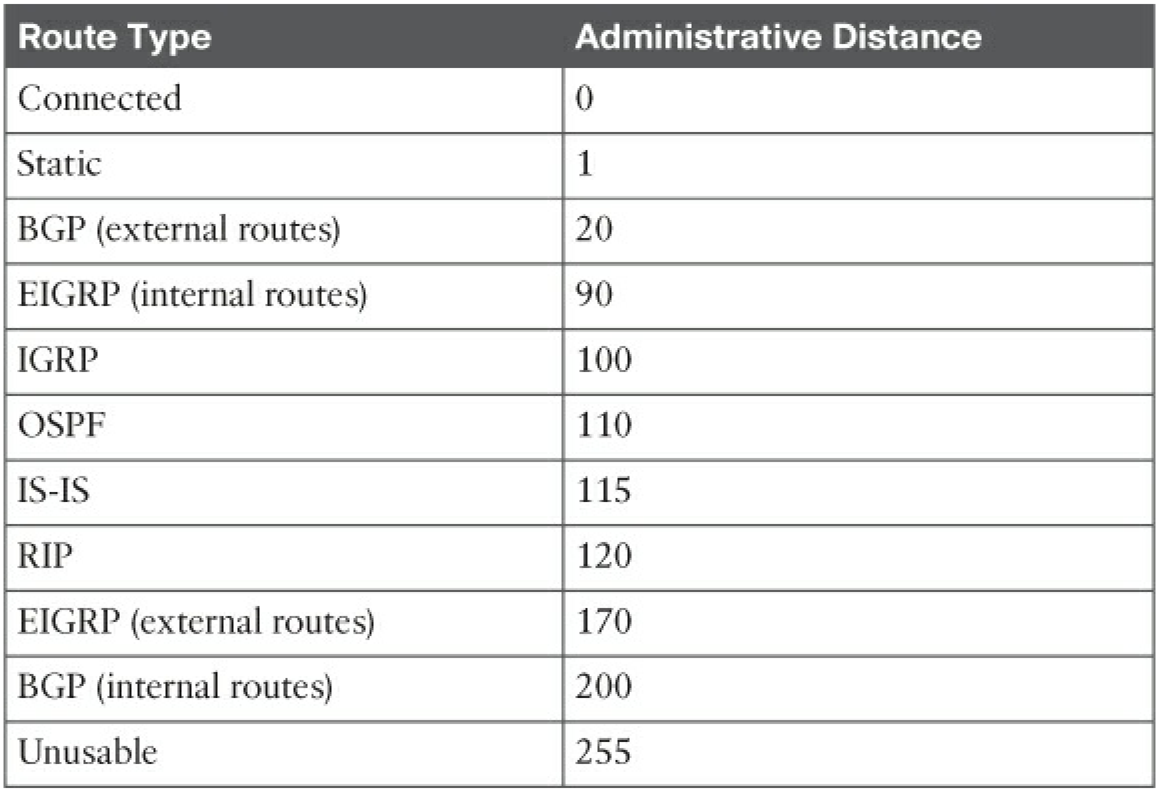
Administrative Distance

Many companies and organizations use a single routing protocol. However, in some cases, a company needs to use multiple routing protocols. For example, if two companies connect their networks so that they can exchange information, they need to exchange some routing information. If one company uses OSPF, and the other uses EIGRP, on at least one router, both OSPF and EIGRP must be used. Then, that router can take routes learned by OSPF and advertise them into EIGRP, and vice versa, through a process called *route redistribution*.

Depending on the network topology, the two routing protocols might learn routes to the same subnets. When a single routing protocol learns multiple routes to the same subnet, the metric tells it which route is best. However, when two different routing protocols learn routes to the same subnet, because each routing protocol's metric is based on different information, IOS cannot compare the metrics. For example, OSPF might learn a route to subnet 10.1.1.0 with metric 101, and EIGRP might learn a route to 10.1.1.0 with metric 2,195,416, but the EIGRP might be the better route—or it might not. There is simply no basis for comparison between the two metrics.

When IOS must choose between routes learned using different routing protocols, IOS uses a concept called *administrative distance*. Administrative distance is a number that denotes how believable an entire routing protocol is on a single router. The lower the number, the better, or more believable, the routing protocol. For example, RIP has a default administrative distance of 120, OSPF uses a default of 110, and EIGRP defaults to 90. When using OSPF and EIGRP, the router will believe the EIGRP route instead of the OSPF route (at least by default). The administrative distance values are configured on a single router and are not exchanged with other routers. Table 17-4 lists the various sources of routing information, along with the default administrative distances.

Table 17-4. Default Administrative Distances



Route Type	Administrative Distance
Connected	0
Static	1
BGP (external routes)	20
EIGRP (internal routes)	90
IGRP	100
OSPF	110
IS-IS	115
RIP	120
EIGRP (external routes)	170
BGP (internal routes)	200
Unusable	255

> **Note**
>
> The **show ip route** command lists each route's administrative distance as the first of the two numbers inside the brackets. The second number in brackets is the metric.

The table shows the default administrative distance values, but IOS can be configured to change the administrative distance of a particular routing protocol, a particular route, or even a static route. For example, the command **ip route 10.1.3.0 255.255.255.0 10.1.130.253** defines a static route with a default administrative distance of 1, but the command **ip route 10.1.3.0 255.255.255.0 10.1.130.253 210** defines the same static route with an administrative distance of 210. So, you can actually create a static route that is only used when the routing protocol does not find a route, just by giving the static route a higher administrative distance.

Understanding the OSPF Link-State Routing Protocol

Routing protocols basically exchange information so routers can learn routes. The routers learn information about subnets, routes to those subnets, and metric information about how good each route is compared to others. The routing protocol can then choose the currently best route to each subnet, building the IP routing table.

This next (second) major section continues to look at routing protocol concepts, now by narrowing the focus to only link-state protocols, specifically OSPF. This section begins by discussing how OSPF routers learn information and choose what routes to add to the routing table. Then, the discussion backs up a bit to a fundamental part of the process: How OSPF routers use neighbor relationships, and how routers must be neighbors before they ever exchange routing information and learn routes. This section ends with some design discussions about how OSPF scales to larger and larger enterprise designs, and how that impacts the details of how link-state protocols work.

Building the LSDB and Creating IP Routes

Link-state protocols build IP routes with a couple of major steps. First, the routers together build a lot of information about the network: routers, links, IP address, status information, and so on. Then the routers flood the information, so all routers know the same information. At that point, each router can calculate routes to all subnets, but from each router's own perspective.

Topology Information and LSAs

Routers using link-state routing protocols need to collectively advertise practically every detail about the internetwork to all the other routers. At the end of the process of *flooding* the information to all routers, every router in the internetwork has the exact same information about the internetwork. Flooding a lot of detailed information to every router sounds like a lot of work, and relative to distance vector routing protocols, it is.

Open Shortest Path First (OSPF), the most popular link-state IP routing protocol, organizes topology information using link-state advertisements (LSA) and the link-state database (LSDB). Figure 17-4 represents the ideas. Each LSA is a data structure with some specific information about the network topology; the LSDB is simply the collection of all the LSAs known to a router. When sitting at the CLI of a router that uses OSPF, the **show ip ospf database** command lists information about the LSDB on that router by listing some of the information in each of the LSAs in the LSDB.

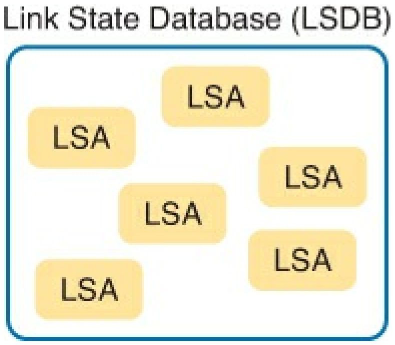


Figure 17-4. LSA and LSDB Relationship

Figure 17-5 shows the general idea of the flooding process, with R8 creating and flooding its router LSA. The router LSA for Router R8 describes the router itself, including the existence of subnet 172.16.3.0/24, as seen on the right side of the figure. (Note that Figure 17-5 actually shows only a subset of the information in R8's router LSA.)

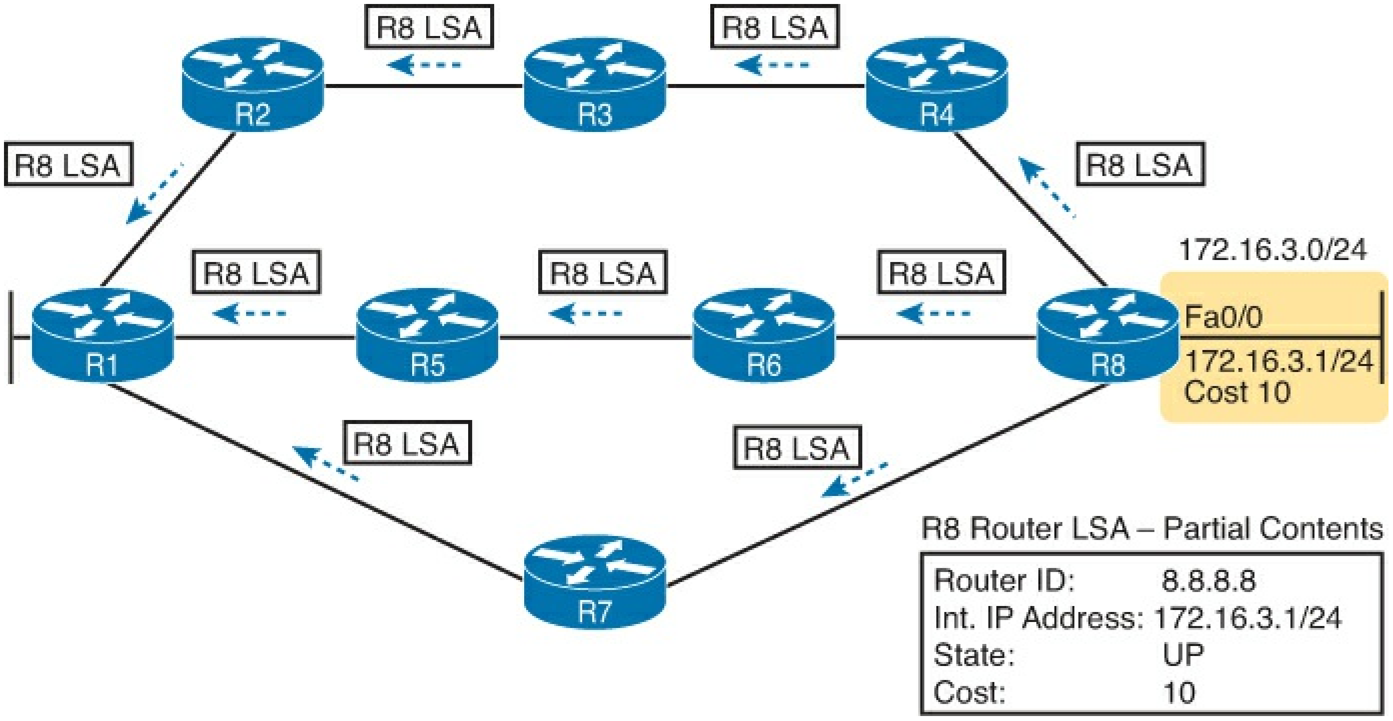


Figure 17-5. Flooding LSAs Using a Link-State Routing Protocol

Figure 17-5 shows the rather basic flooding process, with R8 sending the original LSA for itself, and the other routers flooding the LSA by forwarding it until every router has a copy. The flooding process has a way to prevent loops so that the LSAs do not get flooded around in circles. Basically, before sending an LSA to yet another neighbor, routers communicate, and ask "do you already have this LSA?," and then they avoid flooding the LSA to neighbors that already have it.

Once flooded, routers do occasionally reflood a particular LSA. Routers reflood an LSA when some information changes, for example, when a link goes up or comes down. They also reflood each LSA based on each LSA's separate aging timer (default 30 minutes).

Applying Dijkstra SPF Math to Find the Best Routes

The link-state flooding process results in every router having an identical copy of the LSDB in memory, but the flooding process alone does not cause a router to learn what routes to add to the IP routing table. Although incredibly detailed and useful, the information in the LSDB does not explicitly state each router's best route to reach a destination.

To build routes, link-state routers have to do some math. Thankfully, you and I do not have to know the math! However, all link-state protocols use a type of math algorithm, called the Dijkstra Shortest Path First (SPF) algorithm, to process the LSDB. That algorithm analyzes (with math) the LSDB, and builds the routes that the local router should add to the IP routing table—routes that list a subnet number and mask, an outgoing interface, and a next-hop router IP address.

The ICND2 book discusses the SPF process more, at least to the depth needed to plan OSPF configuration. In particular, that book looks at how to choose OSPF metrics, so changes the decisions made by SPF, allowing an engineer to influence which routes a router chooses as the best route.

Using OSPF Neighbor Relationships

OSPF uses three major categories of internal operation to eventually build routes:

Neighbors: A relationship between two routers that connect to the same data link, created so that the neighboring routers have a means to exchange their LSDBs.

Database exchange: The process of sending LSAs to neighbors so that all routers learn the same LSAs.

Adding the best routes: The process of each router independently running SPF, on their local copy of the LSDB, calculating the best routes, and adding those to the IPv4 routing table.

The previous few pages already discussed the last two items in the list, but neither of those happen until a router has some OSPF neighbor relationships with other routers. In fact, much of the verification and troubleshooting of OSPF revolves around the OSPF neighbor relationship. This section discusses the fundamentals.

The Basics of OSPF Neighbors

OSPF neighbors are routers that both use OSPF and both sit on the same data link. With the data link technology discussed so far in this book, that means two routers connected to the same VLAN become OSPF neighbors, or two routers on the ends of a serial link become OSPF neighbors.

Two routers need to do more than simply exist on the same link to become OSPF neighbors; they must send OSPF messages and agree to become neighbors. To do so, the routers send OSPF Hello messages, introducing themselves to the neighbor. Assuming the two neighbors have compatible OSPF parameters, the two form a neighbor relationship, and would be displayed in the output of the **show ip ospf neighbors** command.

The OSPF neighbor relationship also lets OSPF know when a neighbor might not be a good option for routing packets right now. Imagine R1 and R2 form a neighbor relationship, learn LSAs, and calculate routes that send packets through the other router. Months later, R1 notices that the neighbor relationship with R2 fails. That failed neighbor connection to R2 makes R1 react: R1 refloods LSAs that formerly relied on the link from R1 to R2, and R1 runs SPF to recalculate its own routes.

Finally, the OSPF neighbor model allows new routers to be dynamically discovered. That means new routers can be added to a network without requiring every router to be reconfigured. Instead, the configuration enables OSPF on a router's interfaces, and then the router reacts to any Hello messages from new neighbors, whenever those neighbors happen to be installed.

Meeting Neighbors and Learning Their Router ID

The OSPF Hello process, by which new neighbor relationships are formed, works somewhat like when you move to a new house and meet your various neighbors. When you see each other outside, you might walk over, say hello, and learn each others' names. After talking a bit, you form a first impression, particularly as to whether you think you'll enjoy chatting with this neighbor occasionally, or whether you can just wave and not take the time to talk the next time you see him outside.

Similarly, with OSPF, the process starts with messages called OSPF Hello messages. The Hellos in turn list each router's *Router ID (RID)*, which serves as each router's unique name or identifier for OSPF. Finally, OSPF does several checks of the information in the Hello messages to ensure that the two routers should become neighbors.

OSPF RIDs are 32-bit numbers. As a result, most command output lists these as dotted decimal numbers. Additionally, by default, IOS chooses its OSPF RID based on an interface IPv4 address, because those are some nearby convenient 32-bit numbers as well. However, the OSPF RID can be directly configured, as covered in the later section "Configuring the OSPF Router ID."

As soon as a router has chosen its OSPF RID and some interfaces come up, the router is ready to meet its OSPF neighbors. OSPF routers can become neighbors if they are connected to the same subnet (and in some other special cases not covered on the CCENT and CCNA exams). To discover other OSPF-speaking routers, a router sends multicast OSPF Hello packets to each interface and hopes to receive OSPF Hello packets from other routers connected to those interfaces. Figure 17-6 outlines the basic concept.

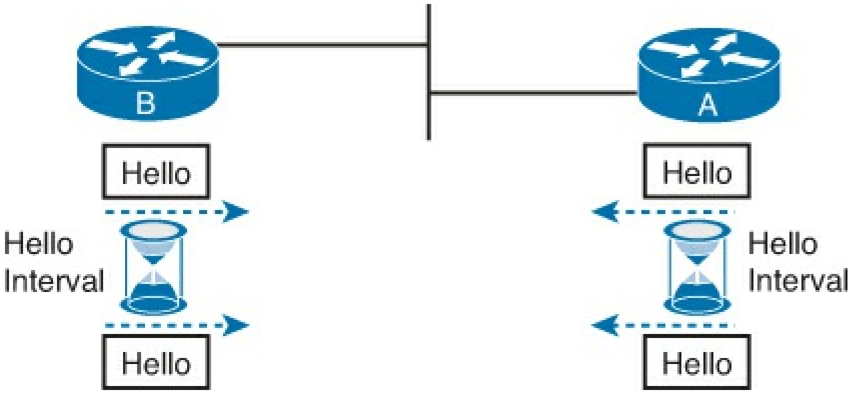


Figure 17-6. OSPF Hello Packets

Routers A and B both send Hello messages onto the LAN. They continue to send Hellos at a regular interval based on their Hello Timer settings. The Hello messages themselves have the following features:

- The Hello message follows the IP packet header, with IP protocol type 89.
- Hello packets are sent to multicast IP address 224.0.0.5, a multicast IP address intended for all OSPF-speaking routers.
- OSPF routers listen for packets sent to IP multicast address 224.0.0.5, in part hoping to receive Hello packets and learn about new neighbors.

The Hello messages contain a variety of OSPF parameters. These details let each router know something about their potential neighbor, including whether the two routers should or should not become neighbors. For example, two OSPF routers will not become neighbors if their interface IPv4 addresses are in different subnets. So, just because two routers happen to hear a Hello from a neighbor does not mean that the two routers will become neighbors. However, if routers do become neighbors, the routers begin to exchange their LSDBs and then calculate any new IP routes.

> **Note**
>
> The ICND2 book discusses routing protocol troubleshooting, with a fair amount of focus on the reasons why OSPF and EIGRP routers might not become neighbors.

Scaling OSPF Through Hierarchical Design

OSPF can be used in some networks with very little thought about design issues. You just turn on OSPF in all the routers, and it works! However, in large networks, engineers need to think about and plan how to use several OSPF features that allow it to scale well. For instance, the OSPF design in Figure 17-7 uses a single OSPF area, because this small internetwork does not need the scalability benefits of OSPF areas.

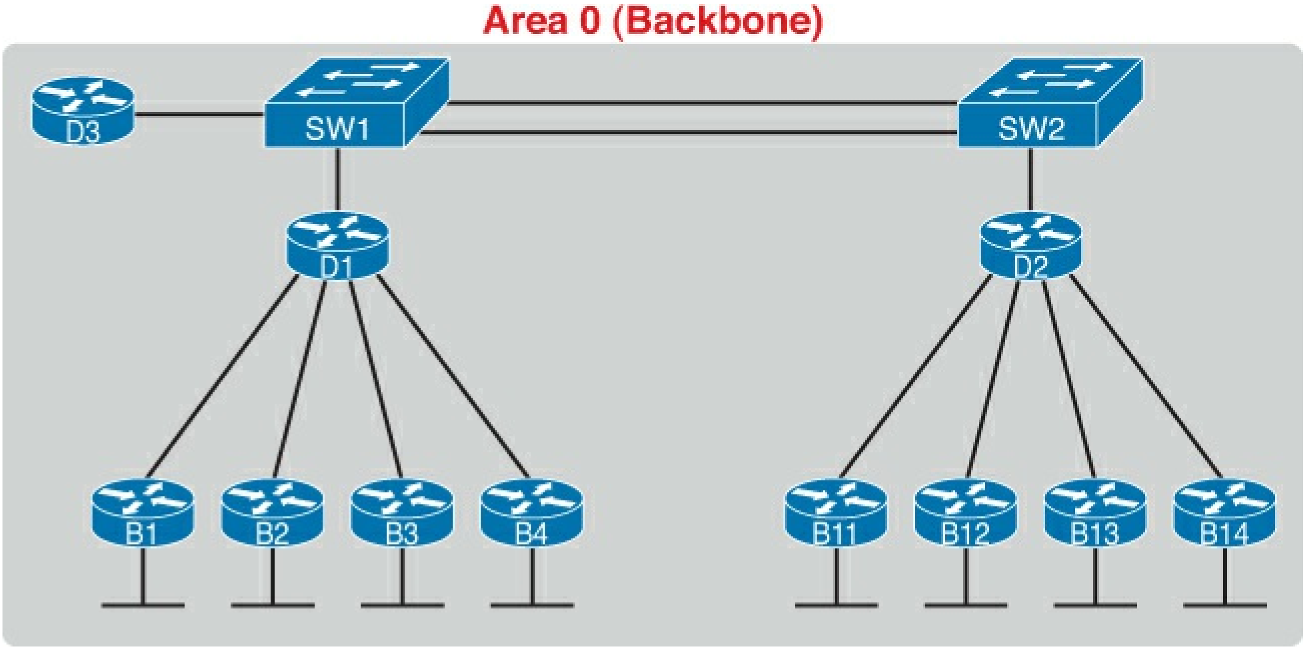


Figure 17-7. Single-Area OSPF

Using a single OSPF area for smaller internetworks, as in Figure 17-7, works well. The configuration is simple, and some of the hidden details in how OSPF works remain simple. In fact, with a small OSPF internetwork, you can just enable OSPF, with all interfaces in the same area, and mostly ignore the idea of an OSPF area.

Now imagine a network with 900 routers instead of only 11, and several thousand subnets. In that size of network, the sheer amount of processing required to run the complex SPF algorithm might cause convergence time to be slow just because of the time it takes each router to process all the math. Also, the routers might experience memory shortages. The problems can be summarized as follows:

- A larger topology database requires more memory on each router.
- Processing the larger-topology database with the SPF algorithm requires processing power that grows exponentially with the size of the topology database.
- A single interface status change (up to down, or down to up) forces every router to run SPF again!

OSPF breaks up the large and complex task of running SPF on a large LSDB by using areas. The engineer places some links one one area, some in another, others in yet a third area, and so on. OSPF then creates a smaller LSDB per-area, rather than one huge LSDB for all links and routers in the internetwork. With smaller topology databases, routers consume less memory and take less processing time to run SPF.

Although there is no exact definition of “large” in this context, networks larger than a few dozen routers benefit from using multiple areas, while even larger networks suffer unless they use multiple areas. (Some documents over the years have listed 50 routers as the most that should be in the same area.) However, note that these numbers of routers are gross generalizations. They depend largely on the network design, the power of the router CPU, the amount of RAM, and so on.

OSPF multiarea design puts all of link—a serial link, and VLAN, and so on—inside an area. To make that work, some routers (Area Border Routers, or ABRs) sit at the border between multiple areas. Routers D1 and D2 serve as ABRs in the area design shown in Figure 17-8, which shows the same network as Figure 17-8, but with three OSPF areas (0, 1, and 2).

Key Topic

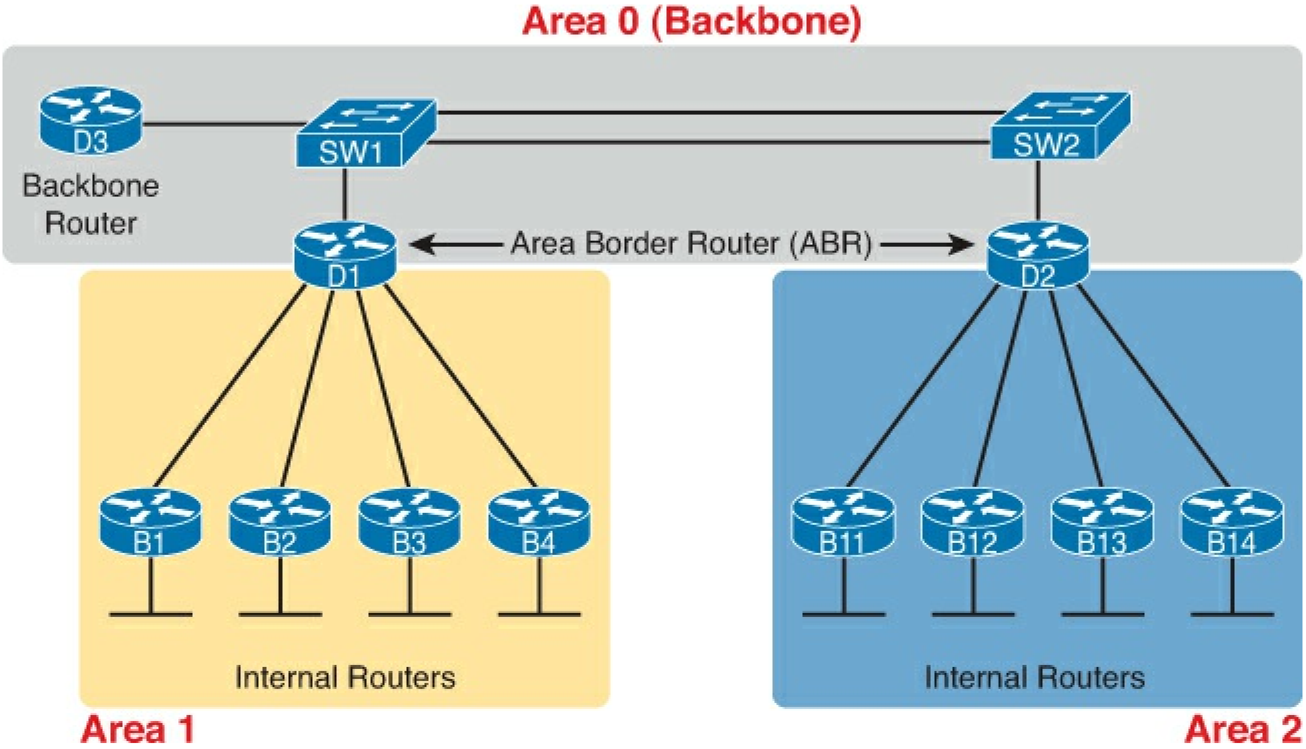


Figure 17-8. Three-Area OSPF

While Figure 17-8 shows a sample area design and some terminology related to areas, it does not show the power and benefit of the areas. By using areas, the OSPF SPF algorithm ignores the details of the topology in the other areas. For example, OSPF on Router B1 (area 1), when doing the complex SPF math processing, ignores the topology information about area 0 and area 2. Each router has far less SPF work to do, so each router more quickly finishes its SPF work, finding the currently-best OSPF routes.

The ICND2 book looks more closely at how SPF works, particularly with more information about LSA types. For now, just know that single-area works great for smaller networks, while multiarea designs overcome the scaling problems that occur as a network grows.

OSPF Configuration

OSPF configuration includes only a few required steps, but it has many optional steps. After an OSPF design has been chosen—a task that can be complex in larger IP internetworks—the configuration can be as simple as enabling OSPF on each router interface and placing that interface in the correct OSPF area.

This section shows several configuration examples, all with a single-area OSPF internetwork. Following those examples, the text goes on to cover several of the additional optional configuration settings. For reference, the following list outlines the configuration steps covered in this chapter, as well as a brief reference to the required commands:

Key Topic

Step 1. Enter OSPF configuration mode for a particular OSPF process using the **router ospf** *process-id* global command.

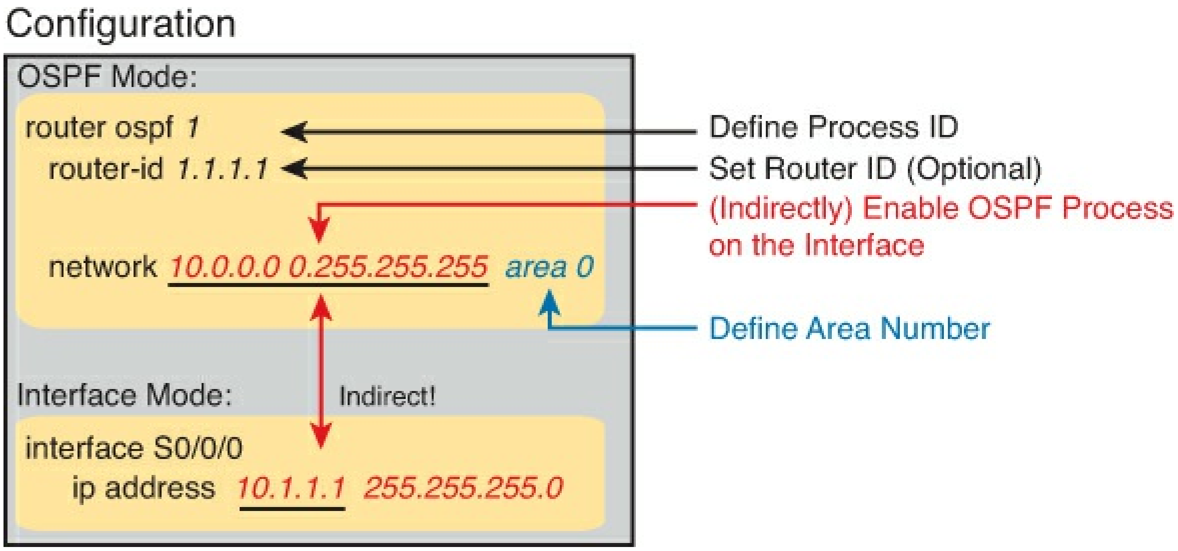
Step 2. (Optional) Configure the OSPF router ID by:

  A. Configuring the **router-id** *id-value* router subcommand

  B. Configuring an IP address on a loopback interface

Step 3. Configure one or more **network** *ip-address wildcard-mask* **area** *area-id* router subcommands, with any matched interfaces being added to the listed area.

For a more visual perspective on OSPFv2 configuration, Figure 17-9 shows the relationship between the key OSPF configuration commands. Note that the configuration creates a routing process in one part of the configuration, and then indirectly enables OSPF on each interface. The configuration does not name the interfaces on which OSPF is enabled, instead requiring IOS to apply some logic by comparing the OSPF **network** command to the interface **ip address** commands. The upcoming example discusses more about this logic.



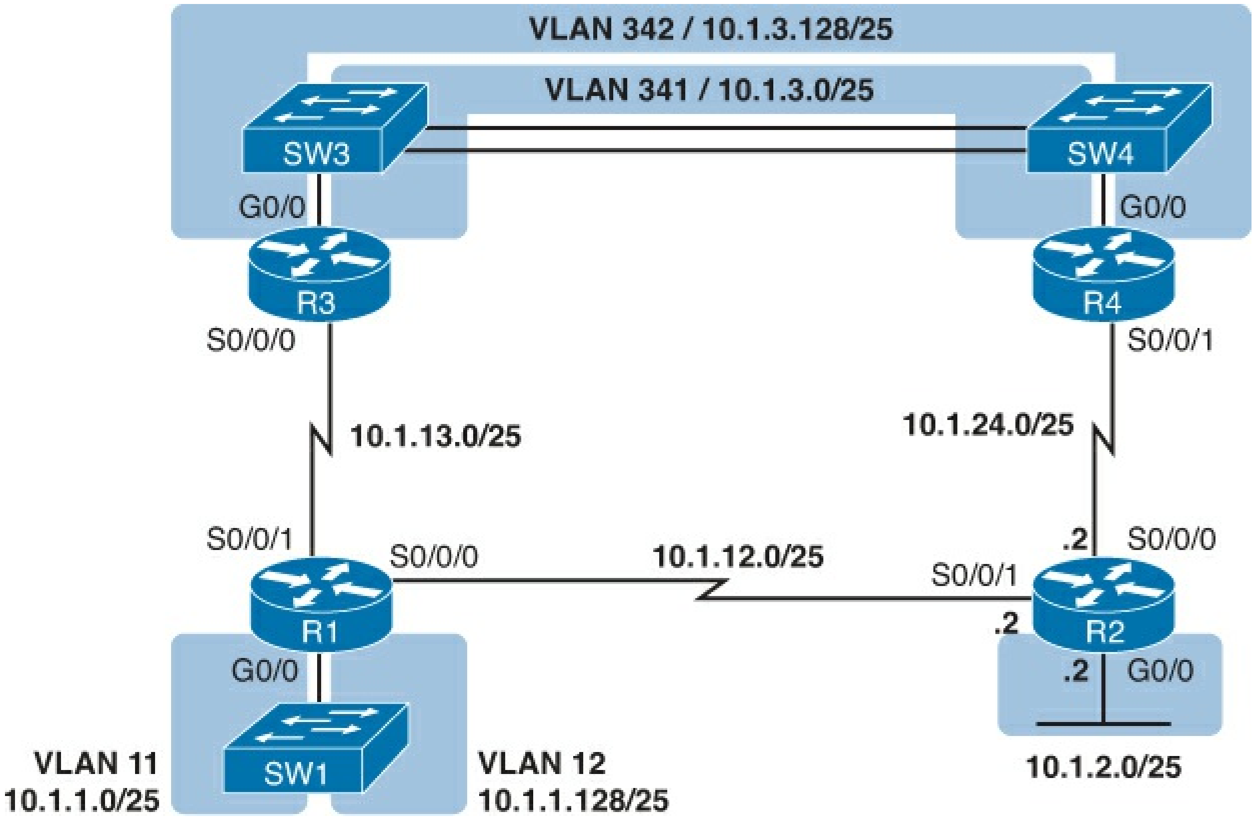
Configuration
OSPF Mode:
Define Process ID
Set Router ID (Optional)
(Indirectly) Enable OSPF Process on the Interface
Define Area Number
Interface Mode:
Indirect!

```
router ospf 1
  router-id 1.1.1.1

  network 10.0.0.0 0.255.255.255 area 0

interface S0/0/0
   ip address 10.1.1.1 255.255.255.0
```

Figure 17-9. Organization of OSPFv2 Configuration

OSPF Single-Area Configuration

Figure 17-10 shows a sample network that will be used for OSPF configuration. All links sit in area 0. It has four routers, each connected to one or two LANs. However, note that routers R3 and R4, at the top of the figure, connect to the same two VLANs/subnets, so they will form neighbor relationships with each other over each of those VLANs as well.



VLAN 342 / 10.1.3.128/25
VLAN 341 / 10.1.3.0/25
SW3
SW4
G0/0
G0/0
R3
R4
S0/0/0
S0/0/1
10.1.13.0/25
10.1.24.0/25
S0/0/1
S0/0/0
10.1.12.0/25
S0/0/1
.2
S0/0/0
.2
R1
R2
G0/0
.2
G0/0
SW1
VLAN 11
10.1.1.0/25
VLAN 12
10.1.1.128/25
10.1.2.0/25

Figure 17-10. Sample Network for OSPF Single-Area Configuration

Example 17-1 shows the IPv4 addressing configuration on Router R3, before getting into the OSPF detail. The configuration enables 802.1Q trunking on R3's G0/0 interface, and assigns an IP address to each. (Not shown, switch S3 has configured trunking on the other side of that Ethernet link.)

Example 17-1. IPv4 Address Configuration on R3 (Including VLAN Trunking)

Click here to view code image

```
interface gigabitethernet 0/0.341
encapsulation dot1q 341
ip address 10.1.3.1 255.255.255.128
!
interface gigabitethernet 0/0.342
```

```
encapsulation dot1q 342
ip address 10.1.3.129 255.255.255.128
!
interface serial 0/0/0
ip address 10.1.13.3 255.255.255.128
```

The beginning single-area configuration on R3, as shown in Example 17-2, enables OSPF on all the interfaces shown in Figure 17-9. First, the **router ospf 1** global command puts the user in OSPF configuration mode, and sets the OSPF *process-id*. This number just needs to be unique on the local router, allowing the router to support multiple OSPF processes in a single router by using different process IDs. (The **router** command uses the *process-id* to distinguish between the processes.) The *process-id* does not have to match on each router, and it can be any integer between 1 and 65,535.

Example 17-2. OSPF Single-Area Configuration on R3 Using One network **Command**

Click here to view code image

```
router ospf 1
network 10.0.0.0 0.255.255.255 area 0
```

Speaking generally rather than about this example, the OSPF **network** command tells a router to find its local interfaces that match the first two parameters on the **network** command. Then, for each matched interface, the router enables OSPF on those interfaces, discovers neighbors, creates neighbor relationships, and assigns the interface to the area listed in the **network** command.

For the specific command in Example17-2, any matched interfaces are assigned to area 0. However, the first two parameters—the *ip_address* and *wildcard_mask* parameter values of 10.0.0.0 and 0.255.255.255—need some explaining. In this case, the command matches all three interfaces shown for router R3; the next topic explains why.

Matching with the OSPF network Command

The OSPF **network** command compares the first parameter in the command to each interface IP address on the local router, trying to find a match. However, rather than comparing the entire number in the **network** command to the entire IPv4 address on the interface, the router can compare a subset of the octets, based on the wildcard mask, as follows:

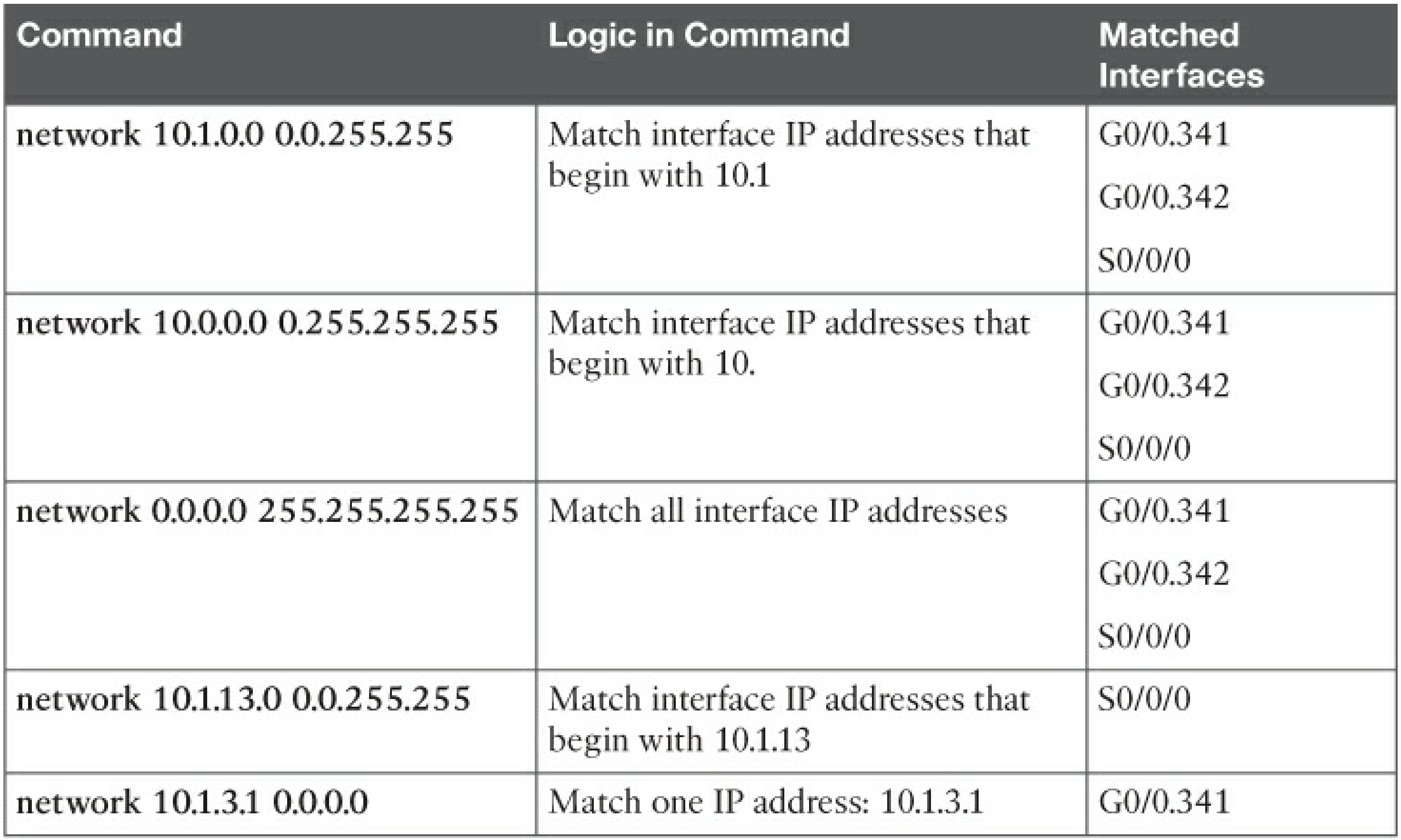
Key Topic

- **Wildcard 0.0.0.0:** Compare all 4 octets. In other words, the numbers must exactly match.
- **Wildcard 0.0.0.255:** Compare the first 3 octets only. Ignore the last octet when comparing the numbers.
- **Wildcard 0.0.255.255:** Compare the first 2 octets only. Ignore the last 2 octets when comparing the numbers.
- **Wildcard 0.255.255.255:** Compare the first octet only. Ignore the last 3 octets when comparing the numbers.
- **Wildcard 255.255.255.255:** Compare nothing—this wildcard mask means that all addresses will match the **network** command.

Basically, a wildcard mask value of 0 in an octet tells IOS to compare to see if the numbers match, and a value of 255 tells IOS to ignore that octet when comparing the numbers.

The **network** command provides many flexible options because of the wildcard mask. For example, in router R3, many **network** commands could be used, with some matching all interfaces, and some matching a subset of interfaces. Table 17-5 shows a sampling of options, with notes.

Table 17-5. Example OSPF network **Commands on R3, with Expected Results**



Command	Logic in Command	Matched Interfaces
network 10.1.0.0 0.0.255.255	Match interface IP addresses that begin with 10.1	G0/0.341 G0/0.342 S0/0/0
network 10.0.0.0 0.255.255.255	Match interface IP addresses that begin with 10.	G0/0.341 G0/0.342 S0/0/0
network 0.0.0.0 255.255.255.255	Match all interface IP addresses	G0/0.341 G0/0.342 S0/0/0
network 10.1.13.0 0.0.255.255	Match interface IP addresses that begin with 10.1.13	S0/0/0
network 10.1.3.1 0.0.0.0	Match one IP address: 10.1.3.1	G0/0.341

The wildcard mask gives the local router its rules for matching its own interfaces. For example, Example 17-2 shows R3 using the **network 10.0.0.0 0.255.255.255 area 0** command. In that same internetwork, Routers R1 and R2 would use the configuration shown in Example 17-3, with two other wildcard masks. In both routers, OSPF is enabled on all the interfaces shown in Figure 17-10.

Example 17-3. OSPF Configuration on Routers R1 and R2

Click here to view code image

```
! R1 configuration next - one network command enables OSPF
! on all three interfaces
router ospf 1
network 10.1.0.0 0.0.255.255 area 0
```

```
! R2 configuration next - One network command per interface
router ospf 1
network 10.1.12.2 0.0.0.0 area 0
network 10.1.24.2 0.0.0.0 area 0
network 10.1.2.2 0.0.0.0 area 0
```

Finally, note that other wildcard mask values can be used as well, so that the comparison happens between specific bits in the 32-bit numbers. Chapter 22, "Basic IPv4 Access Control Lists," discusses wildcard masks in more detail, including these other mask options.

> **Note**
>
> The **network** command uses another convention for the first parameter (the address): if an octet will be ignored because of the wildcard mask octet value of 255, the address parameter should be a 0. However, IOS will actually accept a **network** command that breaks this rule, but then IOS will change that octet of the address to a 0 before putting it into the running configuration file. For example, IOS will change a typed command that begins with **network 1.2.3.4 0.0.255.255** to **network 1.2.0.0 0.0.255.255**.

Verifying OSPF

As mentioned earlier, OSPF routers use a three-step process. First, they create neighbor relationships. Then they build and flood LSAs, so each router in the same area has a copy of the same LSDB. Finally, each router independently computes its own IP routes and adds them to its routing table.

The show **ip ospf neighbor**, **show ip ospf database**, and **show ip route** commands display information for each of these three steps, respectively. To verify OSPF, you can use the same sequence. Or, you can just go look at the IP routing table, and if the routes look correct, OSPF probably worked.

First, examine the list of neighbors known on Router R3. R3 should have one neighbor relationship with R1, over the serial link. It also has two neighbor relationships with R4, over the two different VLANs to which both routers connect. Example 17-4 shows all three.

Example 17-4. OSPF Neighbors on Router R3 from Figure 17-9

Click here to view code image

```
R3# show ip ospf neighbor

Neighbor ID Pri State Dead Time Address Interface
1.1.1.1 0 FULL/ - 00:00:33 10.1.13.1 Serial0/0/0
10.1.24.4 1 FULL/DR 00:00:35 10.1.3.130 GigabitEthernet0/0.342
10.1.24.4 1 FULL/DR 00:00:36 10.1.3.4 GigabitEthernet0/0.341
```

The detail in the output mentions several important facts, and for most people, working right to left works best. For example, looking at the headings:

Interface: This is the local router's interface connected to the neighbor. For example, the first neighbor in the list is reachable through R3's S0/0/0 interface.

Address: This is the neighbor's IP address on that link. Again, for this first neighbor, the neighbor, which is R1, uses IP address 10.1.13.1.

State: While many possible states exist, for the details discussed in this chapter, FULL is the correct and fully-working state in this case.

Neighbor ID: This is the router ID of the neighbor.

Next, Example 17-5 shows the contents of the LSDB on router R3. Interestingly, when OSPF is working correctly in an internetwork with a single area design, all the routers will have the same LSDB contents. So, the **show ip ospf database** command in Example 17-5 should list the same exact information, no matter which of the four routers on which it is issued.

Example 17-5. OSPF Database on Router R3 from Figure 17-10

Click here to view code image

```
R3# show ip ospf database

OSPF Router with ID (10.1.13.3) (Process ID 1)

Router Link States (Area 0)

Link ID ADV Router Age Seq# Checksum Link count
1.1.1.1 1.1.1.1 498 0x80000006 0x002294 6
2.2.2.2 2.2.2.2 497 0x80000004 0x00E8C6 5
10.1.13.3 10.1.13.3 450 0x80000003 0x001043 4
10.1.24.4 10.1.24.4 451 0x80000003 0x009D7E 4

Net Link States (Area 0)

Link ID ADV Router Age Seq# Checksum
10.1.3.4 10.1.24.4 451 0x80000001 0x0045F8
10.1.3.130 10.1.24.4 451 0x80000001 0x00546B
```

For the purposes of this book, do not be concerned about the specifics in the output of this command. However, for perspective, note that the LSDB should list one "Router Link State" (Type 1 Router LSA) for each of the four routers in the design, as highlighted in the example.

Next, Example 17-6 shows R3's IPv4 routing table with the **show ip route** command. Note that it lists connected routes as well as OSPF routes. Take a moment to look back at Figure 17-10, and look for the subnets that are not locally connected to R3. Then look for those routes in the output in Example 17-5.

Example 17-6. IPv4 Routes Added by OSPF on Router R3 from Figure 17-10

Click here to view code image

```
R3# show ip route
```

```
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
E1 - OSPF external type 1, E2 - OSPF external type 2
! Legend lines omitted for brevity


10.0.0.0/8 is variably subnetted, 11 subnets, 2 masks
O 10.1.1.0/25 [110/65] via 10.1.13.1, 00:13:28, Serial0/0/0
O 10.1.1.128/25 [110/65] via 10.1.13.1, 00:13:28, Serial0/0/0
O 10.1.2.0/25 [110/66] via 10.1.3.130, 00:12:41, GigabitEthernet0/0.342
[110/66] via 10.1.3.4, 00:12:41, GigabitEthernet0/0.341
C 10.1.3.0/25 is directly connected, GigabitEthernet0/0.341
L 10.1.3.1/32 is directly connected, GigabitEthernet0/0.341
C 10.1.3.128/25 is directly connected, GigabitEthernet0/0.342
L 10.1.3.129/32 is directly connected, GigabitEthernet0/0.342
O 10.1.12.0/25 [110/128] via 10.1.13.1, 00:13:28, Serial0/0/0
C 10.1.13.0/25 is directly connected, Serial0/0/0
L 10.1.13.3/32 is directly connected, Serial0/0/0
O 10.1.24.0/25
[110/65] via 10.1.3.130, 00:12:41, GigabitEthernet0/0.342
[110/65] via 10.1.3.4, 00:12:41, GigabitEthernet0/0.341
```

First, take a look at the bigger ideas confirmed by this output. The code of "O" on the left identifies a route as being learned by OSPF. The output lists five such IP routes. From the figure, five subnets exist that do not happen to be connected subnets off router R3. Looking for a quick count of OSPF routes, versus nonconnected routes in the diagram, gives a quick check whether OSPF learned all routes.

Next, take a look at the first route (to subnet 10.1.1.0/25). It lists the subnet ID and mask, identifying the subnet. It also lists two numbers in brackets. The first, 110, is the administrative distance of the route. All the OSPF routes in this example use the default of 110. The second number, 65, is the OSPF metric for this route.

Additionally, the **show ip protocols** command is also popular as a quick look at how any routing protocol works. This command lists a group of messages for each routing protocol running on a router. Example 17-7 shows a sample, this time taken from router R3.

Example 17-7. The show ip protocols **Command on R3**

Click here to view code image

```
R3# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "ospf 1"
Outgoing update filter list for all interfaces is not set
Incoming update filter list for all interfaces is not set
Router ID 10.1.13.3
Number of areas in this router is 1. 1 normal 0 stub 0 nssa
Maximum path: 4
Routing for Networks:
10.0.0.0 0.255.255.255 area 0
Routing Information Sources:
Gateway Distance Last Update
1.1.1.1 110 06:26:17
2.2.2.2 110 06:25:30
10.1.24.4 110 06:25:30
Distance: (default is 110)
```

The output shows several interesting facts. The first highlighted line repeats the parameters on the **router ospf 1** global configuration command. The second highlighted item points out R3's router ID, as discussed further in the next section. The third highlighted line repeats more configuration, listing the parameters of the **network 10.0.0.0 0.255.255.255 area 0** OSPF subcommand. Finally, the last highlighted item in the example acts as a heading before a list of known OSPF routers, by router ID.

Configuring the OSPF Router ID

While OSPF has many other optional features, most enterprise networks that use OSPF choose to configure each router's OSPF router ID. OSPF-speaking routers must have a Router ID (RID) for proper operation. By default, routers will choose an interface IP address to use as the RID. However, many network engineers prefer to choose each router's router ID, so command output from commands like **show ip ospf neighbor** lists more recognizable router IDs.

To find its RID, a Cisco router uses the following process when the router reloads and brings up the OSPF process. Note that when one of these steps identifies the RID, the process stops.

Key Topic

1. If the **router-id** *rid* OSPF subcommand is configured, this value is used as the RID.
2. If any loopback interfaces have an IP address configured, and the interface has an interface status of up, the router picks the highest numeric IP address among these loopback interfaces.
3. The router picks the highest numeric IP address from all other interfaces whose interface status code (first status code) is up. (In other words, an interface in up/down state will be included by OSPF when choosing its router ID.)

The first and third criteria should make some sense right away: the RID is either configured or is taken from a working interface's IP address. However, this book has not yet explained the concept of a *loopback interface*, as mentioned in Step 2.

A loopback interface is a virtual interface that can be configured with the **interface loopback** *interface-number* command, where *interface-number* is an integer. Loopback interfaces are always in an "up and up" state unless administratively placed in a shutdown state. For example, a simple configuration of the command **interface loopback 0**, followed by **ip address 2.2.2.2 255.255.255.0**, would create a loopback interface and assign it an IP address. Because loopback interfaces do not rely on any hardware, these interfaces can be up/up whenever IOS is running, making them good interfaces on which to base an OSPF RID.

Example 17-8 shows the configuration that existed in Routers R1 and R2 before the creation of the **show** command output in examples 17-4, 17-5, and 17-6. R1 set is router ID using the direct method, while R2 used a loopback IP address.

Example 17-8. OSPF Router ID Configuration Examples

Click here to view code image

```
! R1 Configuration first
router ospf 1
router-id 1.1.1.1
network 10.1.0.0 0.0.255.255 area 0
network 10.0.0.0 0.255.255.255 area 0
```

```
! R2 Configuration next
!
interface Loopback2
ip address 2.2.2.2 255.255.255.255
```

Each router chooses its OSPF RID when OSPF is initialized, which happens when the router boots or when a CLI user stops and restarts the OSPF process (with the **clear ip ospf process** command). So, if OSPF comes up, and later, the configuration changes in a way that would impact the OSPF RID, OSPF does not change the RID immediately. Instead, IOS waits until the next time the OSPF process is restarted.

Example 17-9 shows the output of the **show ip ospf** command on R1, after the configuration of Example 17-8 was made, and after the router was reloaded, which made the OSPF router ID change.

Example 17-9. Confirming the Current OSPF Router ID

Click here to view code image

```
R1# show ip ospf
Routing Process "ospf 1" with ID 1.1.1.1
! lines omitted for brevity
```

Miscellaneous OSPF Configuration Settings

These last few topics in the chapter discuss a few unrelated and optional OSPF configuration settings, namely how to make a router interface passive for OSPF, and how to originate and flood a default route using OSPF.

OSPF Passive Interfaces

Once OSPF has been enabled on an interface, the router tries to discover neighboring OSPF routers and form a neighbor relationship. To do so, the router sends OSPF Hello messages on a regular time interval (called the Hello interval). The router also listens for incoming Hello messages from potential neighbors.

Sometimes, a router does not need to form neighbor relationships with neighbors on an interface. Often times, no other routers exist on a particular link, so the router has no need to keep sending those repetitive OSPF Hello messages.

When a router does not need to discover neighbors off some interface, the engineer has a couple of configuration options. First, by doing nothing, the router keeps sending the messages, wasting some small bit of CPU cycles and effort. Alternately, the engineer can configure the interface as on OSPF passive interface, telling the router to do the following:

Key Topic

- Quit sending OSPF Hellos on the interface
- Ignore received Hellos on the interface
- Do not form neighbor relationships over the interface

By making an interface passive, OSPF does not form neighbor relationships over the interface, but it does still advertise about the subnet connected to that interface. That is, the OSPF configuration enables OSPF on the interface (using the **network** router subcommand), and then makes the interface passive (using the **passive-interface** router subcommand).

To configure an interface as passive, two options exist. First, you can add the following command to the configuration of the OSPF process, in router configuration mode:

passive-interface *type number*

Alternately, the configuration can change the default setting so that all interfaces are passive by default, and then add a **no passive-interface** command for all interfaces that need to not be passive:

passive-interface default

no passive interface *type number*

For example, in the sample internetwork in Figure 17-10, Router R1, at the bottom left of the figure, has a LAN interface configured for VLAN trunking. The only router connected to both VLANs is Router R1, so R1 will never discover an OSPF neighbor on these subnets. Example 17-10 shows two alternative configurations make the two LAN subinterfaces passive to OSPF.

Example 17-10. Configuring Passive Interfaces on R1 and R2 from Figure 17-10

Click here to view code image

```
! First, make each subinterface passive directly
router ospf 1
passive-interface gigabitethernet0/0.11
passive-interface gigabitethernet0/0.12

! Or, change the default to passive, and make the other interfaces
! not be passive

router ospf 1
passive-interface default
no passive-interface serial0/0/0
no passive-interface serial0/0/1
```

In real internetworks, the choice of configuration style reduces to which option requires the least number of commands. For example, a router with 20 interfaces, 18 of which are passive to OSPF, has far fewer configuration commands when using the **passive-interface default** command to change the default to passive. If only two of those 20 interfaces need to be passive, use the default setting, in which all interfaces are not passive, to keep the configuration shorter.

Interestingly, OSPF makes it a bit of a challenge to use **show** commands to find whether or not an interface is passive. The **show running-config** command lists the configuration directly, but if you cannot get into enable mode to use this command, note these two facts:

The **show ip ospf interface brief** command lists all interfaces on which OSPF is enabled, *including passive interfaces*.

The **show ip ospf interface** command lists a single line that mentions that the interface is passive.

Example 17-11 shows these two commands on Router R1, with the configuration shown in the top of Example 17-10. Note that subinterfaces G0/0.11 and G0/0.12 both show up in the output of **show ip ospf interface brief**.

Example 17-11. Displaying Passive Interfaces

Click here to view code image

```
R1# show ip ospf interface brief
Interface PID Area IP Address/Mask Cost State Nbrs F/C
```

```
Gi0/0.12 1 0 10.1.1.129/25 1 DR 0/0
Gi0/0.11 1 0 10.1.1.1/25 1 DR 0/0
Se0/0/0 1 0 10.1.12.1/25 64 P2P 0/0
Se0/0/1 1 0 10.1.13.1/25 64 P2P 0/0

R1# show ip ospf interface g0/0.11
GigabitEthernet0/0.1 is up, line protocol is up
Internet Address 10.1.1.1/25, Area 0, Attached via Network Statement
Process ID 1, Router ID 10.1.1.129, Network Type BROADCAST, Cost: 1
Topology-MTID Cost Disabled Shutdown Topology Name
0 1 no no Base
Transmit Delay is 1 sec, State DR, Priority 1
Designated Router (ID) 10.1.1.129, Interface address 10.1.1.1
No backup designated router on this network
Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
oob-resync timeout 40
No Hellos (Passive interface)
! Lines omitted for brevity
```

OSPF Default Routes

As discussed in Chapter 16, "Configuring IPv4 Addresses and Routes," in some cases, routers benefit from using a default route. Chapter 16 shows how to configure a router to know a static default route that only that one router uses. This final topic of the chapter looks a different strategy for using default IP routes, one in which an OSPF router creates a default route and also advertises it with OSPF, so that other routers learn default routes dynamically.

The most classic case for using a routing protocol to advertise a default route has to do with an enterprise's connection to the Internet. As a strategy, the enterprise engineer uses these design goals:

- All routers learn specific routes for subnets inside the company; a default route is not needed when forwarding packets to these destinations.
- One router connects to the Internet, and it has a default route that points toward the Internet.
- All routers should dynamically learn a default route, used for all traffic going to the Internet, so that all packets destined to locations in the Internet go to the one router connected to the Internet.

Figure 17-11 shows the idea of how OSPF advertises the default route, with the specific OSPF configuration. In this case, a company connects to an ISP with their Router R1. That router uses the OSPF **default-information originate** command (Step 1). As a result, the routers advertise a default route using OSPF (Step 2) to the remote routers (B1, B2, and B3).

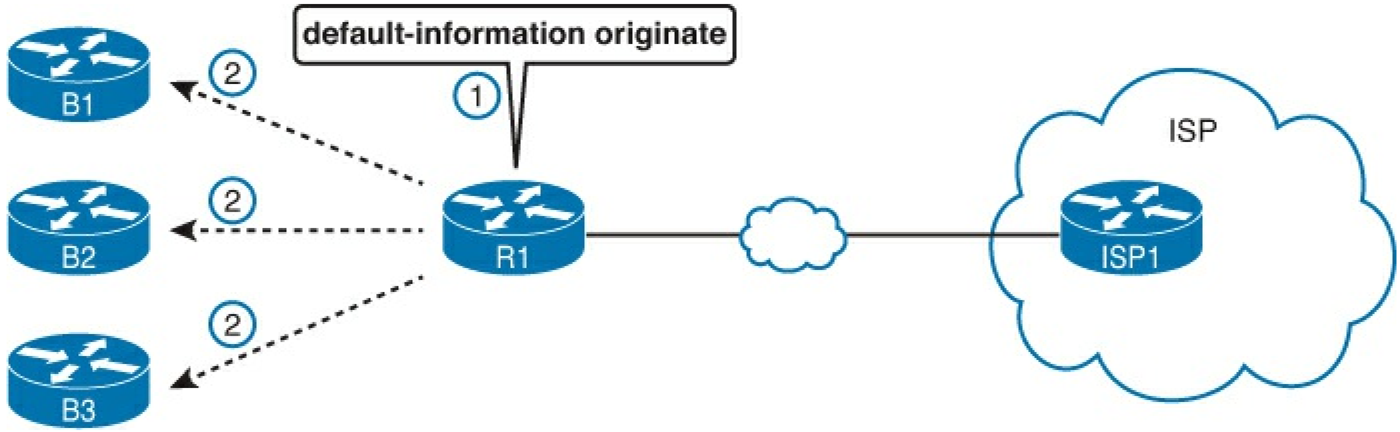


Figure 17-11. Using OSPF to Create and Flood a Default Route

Figure 17-12 shows the default routes that result from OSPF's advertisements in Figure 17-11. On the far left, the three branch routers all have OSPF-learned default routes, pointing to R1. R1 itself also needs a default route, pointing to the ISP router, so that R1 can forward all Internet-bound traffic to the ISP.

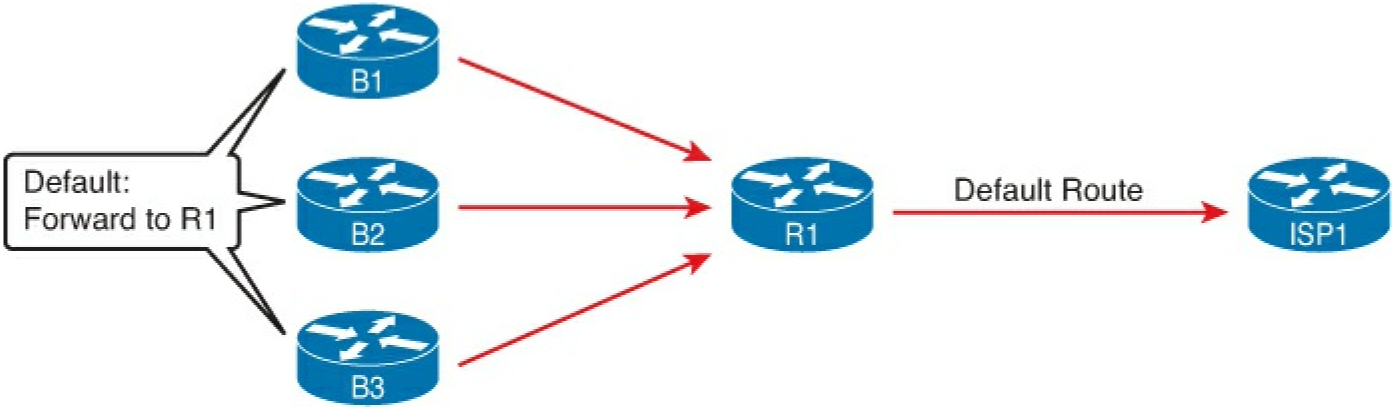


Figure 17-12. Default Routes Resulting from the default-information originate **Command**

Finally, this feature gives the engineer control over when the router originates this default route First, R1 needs a default route, either defined as a static default route or learned from the ISP. The **default-information originate** command then tells the R1 to advertise a default route when its own default route is working, and to advertise it as down when its own default route fails.

> **Note**
>
> Interestingly, the **default-information originate always** router subcommand tells the router to always advertise the default route, no matter whether the router's default route is working or not.

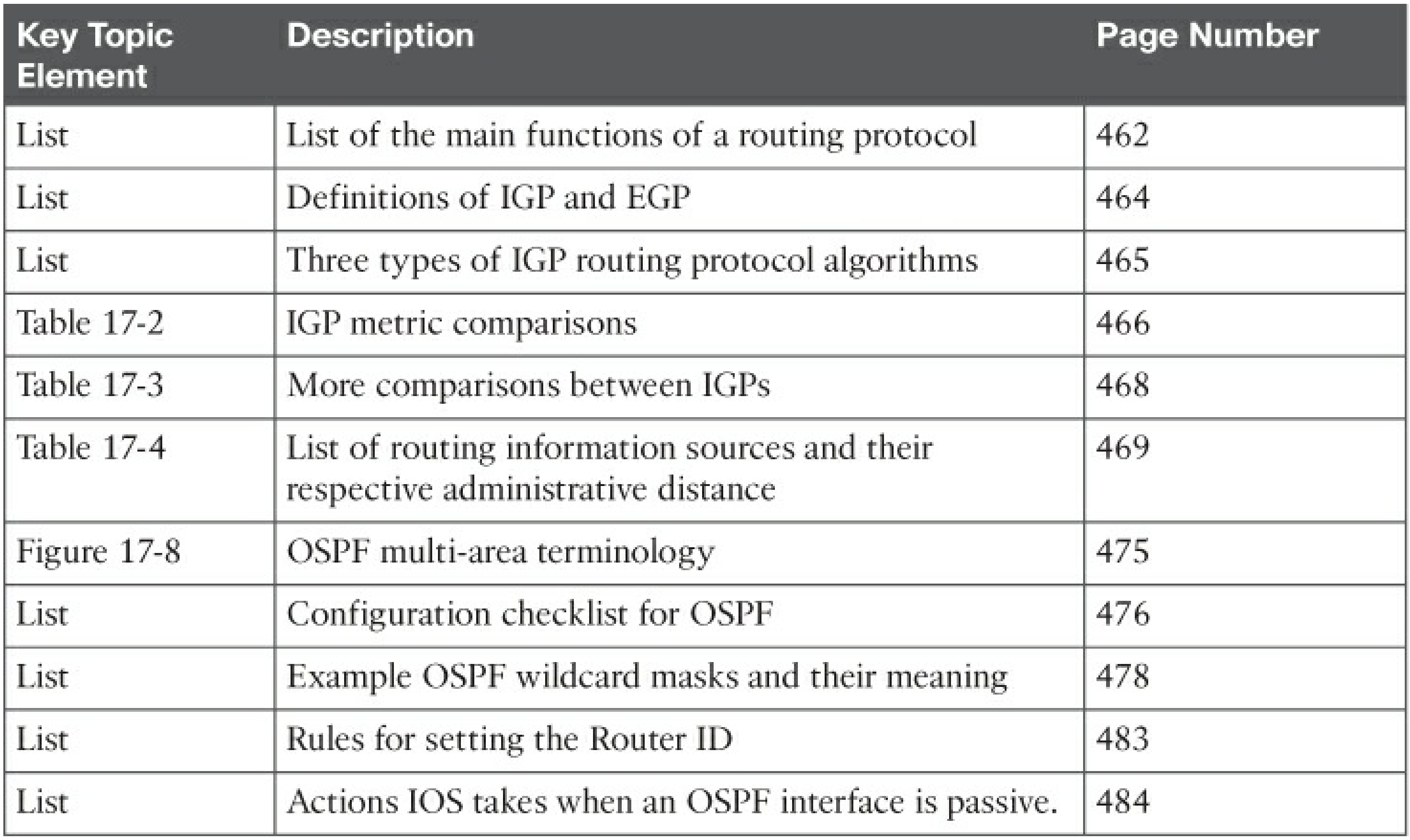
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 17-6 lists these key topics and where each is discussed.

Key Topic

Table 17-6. Key Topics for Chapter 17



Key Topic Element	Description	Page Number
List	List of the main functions of a routing protocol	462
List	Definitions of IGP and EGP	464
List	Three types of IGP routing protocol algorithms	465
Table 17-2	IGP metric comparisons	466
Table 17-3	More comparisons between IGPs	468
Table 17-4	List of routing information sources and their respective administrative distance	469
Figure 17-8	OSPF multi-area terminology	475
List	Configuration checklist for OSPF	476
List	Example OSPF wildcard masks and their meaning	478
List	Rules for setting the Router ID	483
List	Actions IOS takes when an OSPF interface is passive.	484

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists for you to check your work.

Definitions of Key Terms

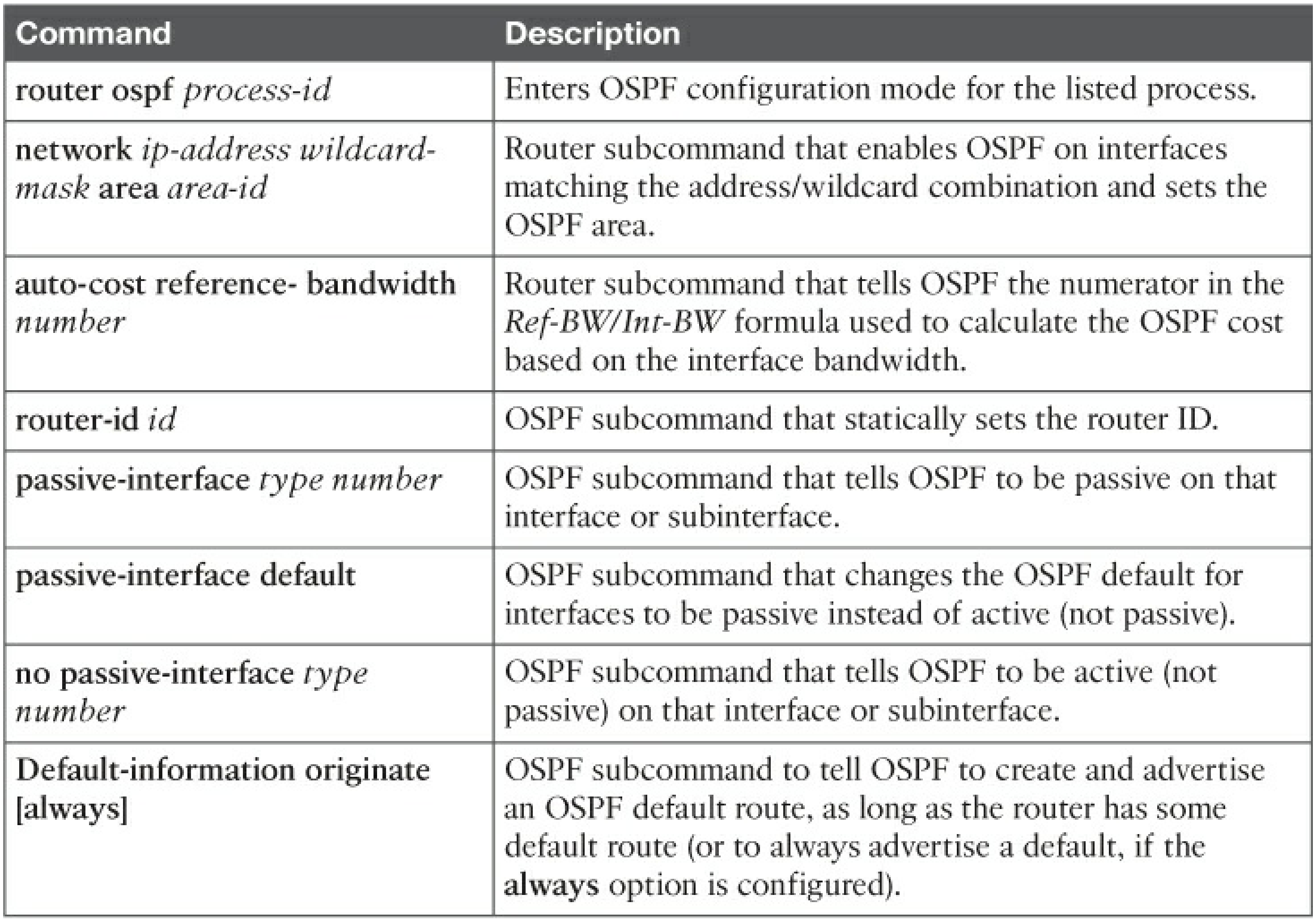
After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

convergence
Shortest Path First (SPF) algorithm
distance vector
interior gateway protocol (IGP)
link-state
link-state advertisement (LSA)
link-state database (LSDB)
metric
routed protocol
routing protocol
Area Border Router (ABR)
neighbor
router ID (RID)

Command Reference to Check Your Memory

Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To check to see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table with a piece of paper, read the descriptions on the right side, and see whether you remember the command.

Table 17-7. Chapter 17 Configuration Command Reference



Command	Description
router ospf *process-id*	Enters OSPF configuration mode for the listed process.
network *ip-address wildcard-mask* **area** *area-id*	Router subcommand that enables OSPF on interfaces matching the address/wildcard combination and sets the OSPF area.
auto-cost reference- bandwidth *number*	Router subcommand that tells OSPF the numerator in the *Ref-BW/Int-BW* formula used to calculate the OSPF cost based on the interface bandwidth.
router-id *id*	OSPF subcommand that statically sets the router ID.
passive-interface *type number*	OSPF subcommand that tells OSPF to be passive on that interface or subinterface.
passive-interface default	OSPF subcommand that changes the OSPF default for interfaces to be passive instead of active (not passive).
no passive-interface *type number*	OSPF subcommand that tells OSPF to be active (not passive) on that interface or subinterface.
Default-information originate [always]	OSPF subcommand to tell OSPF to create and advertise an OSPF default route, as long as the router has some default route (or to always advertise a default, if the **always** option is configured).

Table 17-8. Chapter 17 EXEC Command Reference

Command	Description
show ip route [ospf]	Lists routes in the routing table learned by OSPF.
show ip protocols	Shows routing protocol parameters and current timer values.
show ip ospf interface [*type number*]	Lists a large group of messages per interface (or just for the one listed interface), with many facts: the area in which the interface resides, neighbors adjacent on this interface, and Hello and dead timers.
show ip ospf interface brief	Lists one line per interface on which OSPF is enabled, for all interfaces (including passive interfaces) on which OSPF is enabled.
show ip ospf neighbor [*neighbor-RID*]	Lists neighbors and current status with neighbors, per interface, and optionally lists details for the router ID listed in the command.
show ip ospf database	Lists a summary of the LSAs in the local router's LSDB, listing one line for each LSA.
show ip ospf	Lists a variety of facts about the local router's OSPF process, notably with the first line listing the router's router ID.
show ip protocols	Lists a group of messages for every instance of every routing protocol running in the router, restating many configuration parameters, default configuration settings when used, and listing the known OSPF routers in that area.

Chapter 18. Configuring and Verifying Host Connectivity

This chapter covers the following exam topics:

LAN Switching Technologies

- Verify network status and switch operation using basic utilities such as ping, telnet and ssh.

IP Routing Technologies

- Configure and verify utilizing the CLI to set basic Router configuration
  - Cisco IOS commands to perform basic router setup
- Verify router configuration and network connectivity
  - Cisco IOS commands to review basic router information and network connectivity

IP Services

- Configure and verify DHCP (IOS Router)
  - configuring router interfaces to use DHCP
  - DHCP options
  - excluded addresses
  - lease time

Troubleshooting

- Troubleshoot and correct common problems associated with IP addressing and host configurations.

In the world of TCP/IP, the word *host* refers to any device with an IP address: your phone, your tablet, a PC, a router, a switch, or a wireless access point. Hosts even include some less obvious devices as well: the electronic advertising video screen at the mall, your electrical power meter that uses the same technology as mobile phones to submit your electrical usage information for billing, your new car.

No matter the type of host, any host that uses IPv4 needs four IPv4 settings to work properly:

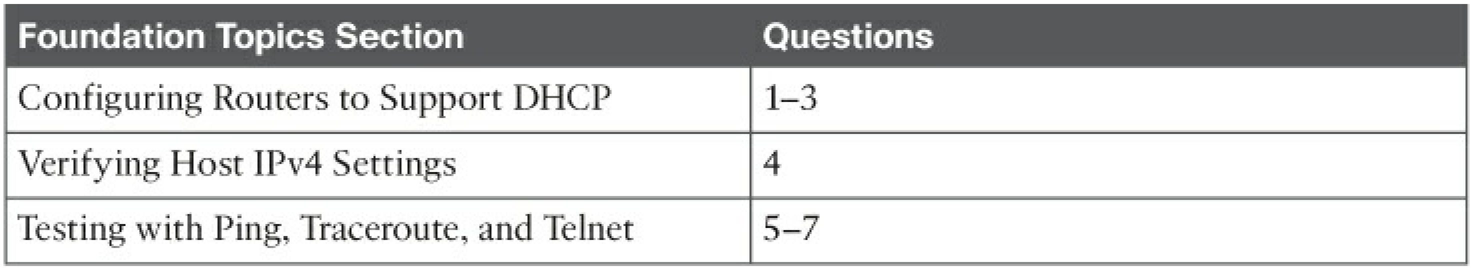
- IP address
- Subnet mask
- Default router(s)
- DNS server IP address(es)

This last chapter in this part of the book completes the discussion of how to build a basic IPv4 network by focusing on the IPv4 settings on hosts. In particular, this chapter begins by discussing how a host can dynamically learn these four settings using the Dynamic Host Configuration Protocol, or DHCP. The middle section of the chapter then discusses some tips for how to verify that a host has all four of these IPv4 settings. The third and final section of this chapter then looks at three testing and verification tools—ping, traceroute, and Telnet—to learn how they can help verify whether the IP settings that do exist actually work.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 18-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Configuring Routers to Support DHCP	1–3
Verifying Host IPv4 Settings	4
Testing with Ping, Traceroute, and Telnet	5–7

1. A PC connects to a LAN and uses DHCP to lease an IP address for the first time. Of the usual four DHCP messages that flow between the PC and the DHCP server, which ones do the client send? (Choose 2 answers.)

   a. Acknowledgment
   b. Discover
   c. Offer
   d. Request

2. An enterprise puts the DHCP and DNS servers on VLAN 10/subnet 10 in Atlanta, using IP address 10.1.10.1 for the DHCP server and 10.1.10.2 for the DNS server. A remote router sits in Boston, with devices on the Boston LAN using

the DHCP and DNS servers in Atlanta. Which of the following needs to be configured in the routers in this enterprise to support DHCP and DNS?

- **a.** The **ip helper-address 10.1.10.1** command in the Atlanta router
- **b.** The **ip helper-address 10.1.10.2** command in the Boston router
- **c.** The **ip name-server 10.1.10.2** command in the Atlanta router
- **d.** The **ip dhcp-server 10.1.10.1** command in the Boston router
- **e.** None of the other answers is correct.

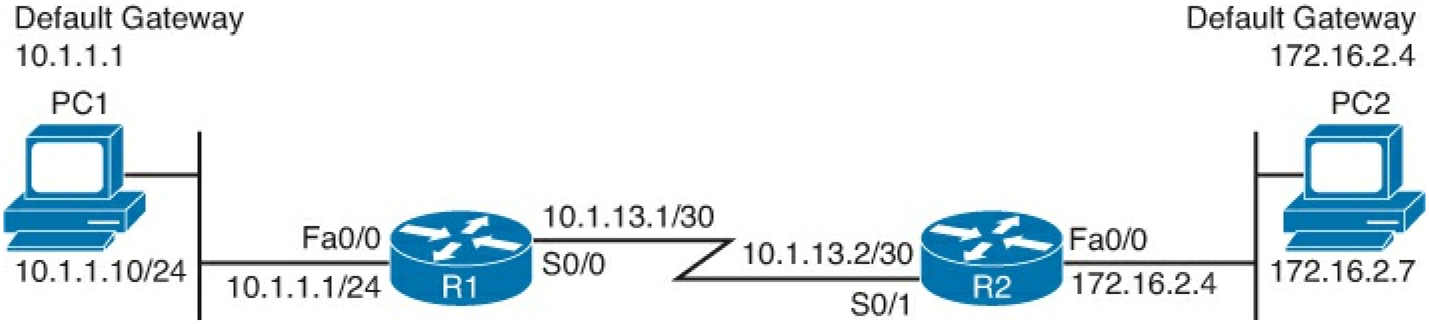
3. Fred decides to migrate from an old DHCP server platform to use a Cisco router at the headquarters building. This DHCP server, created with configuration in IOS on a Cisco router, supports 200 remote subnets. Which of the following settings are made outside of a per-subnet pool of addresses?

- **a.** Client IP address
- **b.** Addresses in that subnet excluded from being leased by the server
- **c.** Default router
- **d.** DNS server
- **e.** Length of address lease

4. PC1 uses manual (static) IPv4 configuration associated with its Ethernet NIC. Which of the following IPv4 settings will the PC list in the IPv4 configuration? (Choose 2 answers.)

- **a.** A DHCP server address
- **b.** A DNS server address
- **c.** A traceroute server address
- **d.** The PC's own IP address

Use the following figure to answer Questions 5 and 6:



5. A new network engineer is trying to troubleshoot a problem for the user of PC1. Which of the following tasks and results would most likely point to a Layer 1 or 2 Ethernet problem on the LAN on the left side of the figure?

- **a.** A **ping 10.1.1.1** command on PC1 did not succeed.
- **b.** A **ping 10.1.13.2** command from PC1 succeeded, but a **ping 172.16.2.4** did not.
- **c.** A **ping 10.1.1.1** command from PC1 succeeded, but a **ping 10.1.13.1** did not.
- **d.** A **ping 10.1.1.10** command from PC1 succeeded.

6. The PC2 user issues the **tracert 10.1.1.10** command. Which of the following IP addresses could be shown in the command output? (Choose three answers.)

- **a.** 10.1.1.10
- **b.** 10.1.1.1
- **c.** 10.1.13.1
- **d.** 10.1.13.2
- **e.** 172.16.2.4

7. Examine the following command output. If the user typed the **resume** command, what would happen?

Click here to view code image

```
R1# show sessions
Conn Host Address Byte Idle Conn Name
1 Fred 10.1.1.1 0 0 Fred
* 2 Barney 10.1.2.1 0 0 Barney
```

- **a.** The command would be rejected, and the R1 CLI command prompt would be displayed again.
- **b.** The CLI user would be connected to a suspended Telnet connection to the router with IP address 10.1.1.1.
- **c.** The CLI user would be connected to a suspended Telnet connection to the router with IP address 10.1.2.1.
- **d.** The result cannot be accurately predicted from the information shown.

Answers to the "Do I Know This Already?" quiz:

1 B and D 2 E 3 B 4 B and D 5 A 6 A, C, and E 7 C

Foundation Topics

Configuring Routers to Support DHCP

Dynamic Host Configuration Protocol (DHCP) is one of the most commonly used protocols in a TCP/IP network. The vast majority of hosts in a TCP/IP network are user devices, and the vast majority of user devices learn their IPv4 settings using DHCP.

Using DHCP has several advantages over using manually or statically configured IPv4 settings. The configuration of host IP settings sits in a DHCP server, with the client learning these settings using DHCP messages. As a result, the host IP configuration is controlled by the IT staff, which cuts down on user errors. DHCP allows both the permanent assignment of host addresses, but more commonly, DHCP assigns a temporary lease of IP addresses. With these leases, the DHCP server can reclaim IP addresses when a device is removed from the network, making better use of the available addresses.

DHCP also enables mobility. For example, every time a user moves to a new location with a tablet computer—to a coffee shop, a client location, or back at the office—the user's device can connect to the wireless LAN, use DHCP to lease a new IP address, and begin working on the new network. Without DHCP, the user would have to ask for information about the local network, configure settings manually, with more than a few users making mistakes.

Although DHCP works automatically for user hosts, it does require some preparation from the network, with some configuration on routers. In some enterprise networks, that router configuration can be a single command on many of the router's LAN interfaces (**ip helper-address** *server-ip*), which identifies the DHCP server by its IP address. In other cases, the router actually plays the role of the DHCP server. Regardless, the routers have some role to play.

This first major section of the chapter begins with a look at the DHCP protocols that run between a DHCP client (any host) and the DHCP server. The next topic looks at the minimum router configuration option, which uses a separate appliance or server as the DHCP server. The final part of this section looks at how to configure a Cisco router to be that DHCP server.

DHCP Protocol Messages and Addresses

Sit back for a moment, and think about the role of DHCP for a host computer. The host acts as a DHCP client. As DHCP client, the host begins with no IPv4 settings: no IPv4 address, no mask, no default router, and no DNS server IP addresses. But a DHCP client does have knowledge of the DHCP protocol, so the client can use that protocol to (a) discover a DHCP server and (b) request to lease an IPv4 address.

The DHCP process to lease an IP address uses the following four messages between the client and server. (Also, as a way to help remember the messages, note that the first letters spell DORA):

Discover: Sent by the DHCP client to find a willing DHCP server

Offer: Sent by a DHCP server to offer to lease to that client a specific IP address (and inform the client of its other parameters)

Request: Sent by the DHCP client to ask the server to lease the IPv4 address listed in the Offer message

Acknowledgment: Sent by the DHCP Server to assign the address, and to list the mask, default router, and DNS server IP addresses

DHCP clients, however, have a somewhat unique problem: they do not have an IP address yet, but they need to send IP packets. To make that work, DHCP messages make use of two special IPv4 addresses that allow a host that has no IP address still be able to send and receive messages on the local subnet:

0.0.0.0: An address reserved for use as a source IPv4 address for hosts that do not yet have an IP address.

255.255.255.255: The address reserved as a local subnet broadcast address. Packets sent to this destination address are broadcast on the local data link, but routers do not forward them to other subnets.

To see how these addresses work, Figure 18-1 shows an example of the IP addresses used between a host (A) and a DHCP server on the same LAN. Host A, a client, sends a Discover message, with source IP address of 0.0.0.0 because host A does not have an IP address to use yet. Host A sends the packet to destination 255.255.255.255, which is sent in a LAN broadcast frame, reaching all hosts in the subnet. The client hopes that there is a DHCP server on the local subnet. Why? Packets sent to 255.255.255.255 only go to hosts in the local subnet; Router R1 will not forward this packet.

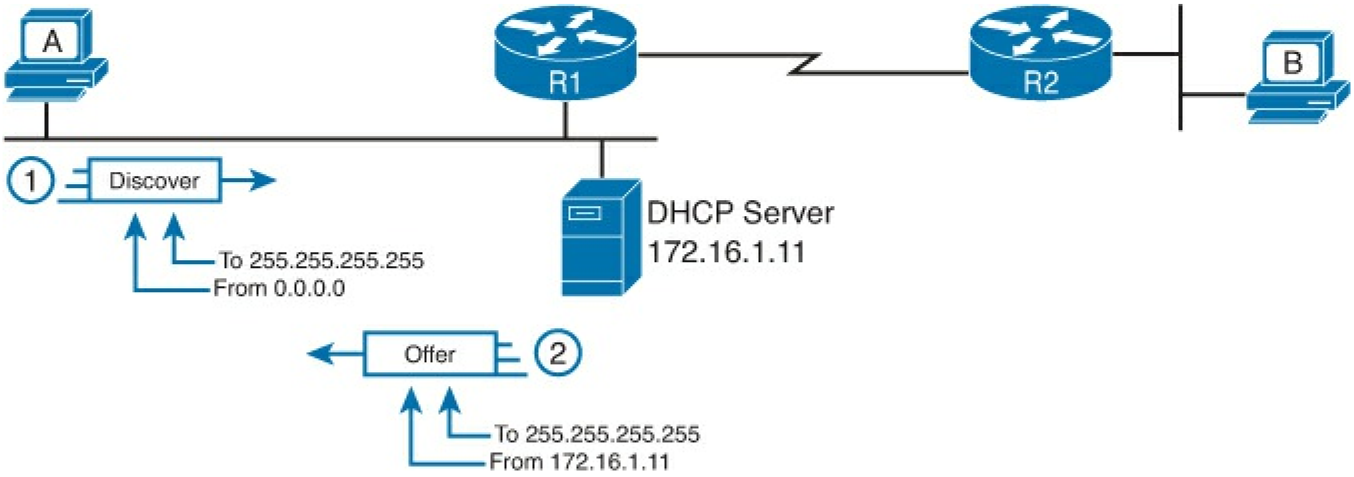


Figure 18-1. DHCP Discover and Offer

> **Note**
>
> Figure 18-1 shows just one example of the addresses that can be used, specifically when the DHCP client chooses to use a DHCP option called the broadcast flag. This chapter does not attempt to show every variation of addresses used by the DHCP protocols; instead, the goal is to show one typical example, so you see the need for a particular function on the router, called DHCP Relay. However, note that all the DHCP examples in this chapter show the addresses used if client uses the DHCP broadcast flag.

Now look at the Offer message sent back by the DHCP server. The server sets the destination IP address to 255.255.255.255 again. Why? Host A still does not have an IP address, so the server cannot send a packet directly to host A. So, the server sends the packet to “all hosts on the local subnet” (255.255.255.255), a packet that is also encapsulated in an Ethernet broadcast frame. Host A will be able to receive and process the message. (Other hosts receive and ignore the message.)

The DHCP messages work well, as shown in the figure, when the DHCP client and server sit in the same subnet. Once the four messages are complete, the DHCP client has an IP address, plus its other IPv4 settings, and it can send unicast IP packets as normal.

Supporting DHCP for Remote Subnets with DHCP Relay

Network engineers have a major design choice to make with DHCP: Do they put a DHCP server in every LAN subnet, or locate a DHCP server in a central site? With a DHCP server in every subnet, the protocols work as shown in Figure 18-1, and the router can ignore DHCP completely. However, with a centralized DHCP server, many DHCP clients sit in a different subnet than the DHCP server. So far in this section, it appears that the DHCP message would never reach the DHCP server, because routers do not route (forward) IPv4 packets sent to destination IP address 255.255.255.255.

Many enterprise networks use a couple of DHCP servers at a centralized site, supporting DHCP services to all remote subnets. The routers need to somehow forward those DHCP messages between clients and the DHCP server. To make that work, the routers connected to the remote LAN subnets need an interface subcommand: the **ip helper-address** *server-ip* command.

The **ip helper-address** *server-ip* subcommand tells the router to do the following for the messages coming in an interface, from a DHCP client:

Key Topic

1. Watch for incoming DHCP messages, with destination IP address 255.255.255.255.
2. Change that packet’s source IP address to the router’s incoming interface IP address.
3. Change that packet’s destination IP address to the address of the DHCP server (as configured in the **ip helper-address** command).
4. Route the packet to the DHCP server.

This command gets around the “do not route packets sent to 255.255.255.255” rule by changing the destination IP address. Once the destination has been set to match the DHCP server’s IP address, the network can route the packet to the server.

> **Note**

> This feature, by which a route relays DHCP messages by changing the IP addresses in the packet header, is called *DHCP relay*.

Figure 18-2 shows an example of the process. Host A sits on the left, as a DHCP client. The DHCP server (172.16.2.11) sits on the right. R1 has an **ip helper-address 172.16.2.11** command configured, under its G0/0 interface. At Step 1, Router R1 notices the incoming DHCP packet destined for 255.255.255.255. Step 2 shows the results of changing both the source and destination IP address, with R1 routing the packet.

Key Topic

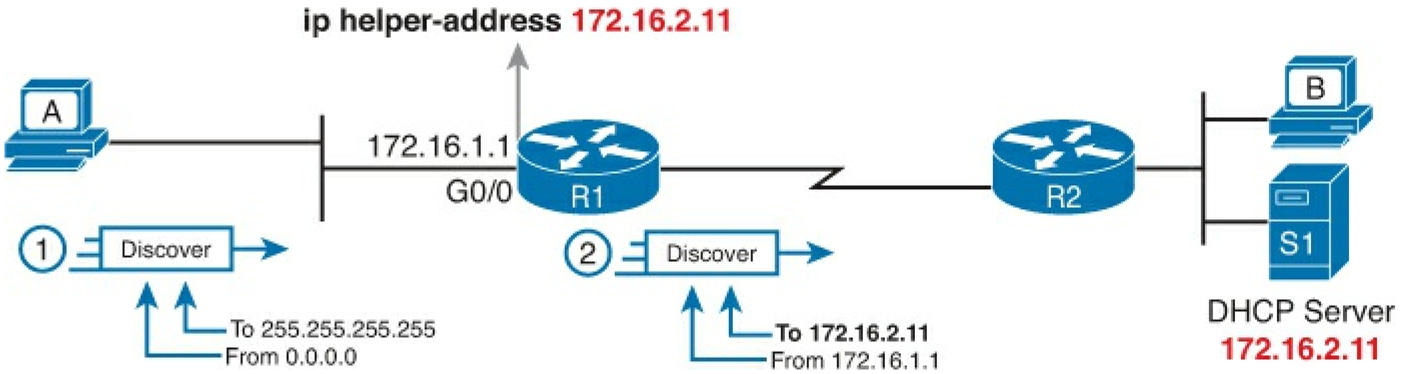


Figure 18-2. IP Helper Address Effect

The router uses a similar process for the return DHCP messages from the server. First, for the return packet from the DHCP server, the server simply reverses the source and destination IP address of the packet received from the router (relay agent). For example, in Figure 18-2, the Discover message lists source IP address 172.16.1.1, so the server sends the Offer message back to destination IP address 172.16.1.1.

When a router receives a DHCP message, addressed to one of the router's own IP addresses, the router realized the packet might be part of the DHCP relay feature. When that happens, the DHCP relay agent (Router R1) needs to change the destination IP address, so that the real DHCP client (host A), which does not have an IP address yet, can receive and process the packet. Figure 18-3 shows one example of how these addresses work, when R1 receives the DHCP Offer message sent to R1's own 172.16.1.1 address. R1 changes the packet's destination to 255.255.255.255, and forwards it out G0/0, knowing that all hosts (including the DHCP client A) will receive the message.

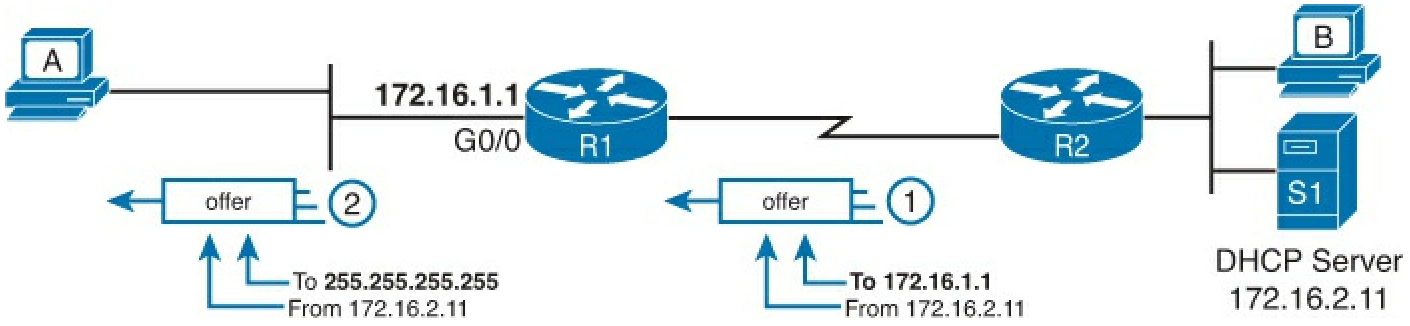


Figure 18-3. IP Helper Address for the Offer Message Returned from the DHCP Server

Many enterprise networks use a centralized DHCP server, so the normal router configuration includes an **ip helper-address** command on every LAN interface/subinterface. With that standard configuration, user hosts off any router LAN interface can always reach the DHCP server and lease an IP address.

Information Stored at the DHCP Server

A DHCP server might sound like some large piece of hardware, sitting in a big locked room with lots of air conditioning to keep the hardware cool. However, like most servers, the server is actually software, running on some server OS. The DHCP server could be a piece of software downloaded for free and installed on an old PC. However, because the server needs to be available all the time, to support new DHCP clients, most companies install the software on a very stable and highly available server environment, but the DHCP service is still created by software.

To be ready to answer DHCP clients, and to supply them with an IPv4 address and other information, the DHCP server (software) needs information. DHCP servers typically organize these IPv4 settings per subnet, because the information the server tells the client is usually the same for all hosts in the same subnet. For example, IP addressing rules tell us that all hosts on the same subnet should use the same mask.

The following list shows the types of settings the DHCP server needs to know to support DHCP clients:

- **Subnet ID and mask:** The DHCP server can use this information to know all addresses in the subnet. Usually, unless reserved or excluded, the server believes that it can lease any and all valid addresses in the subnet. (The DHCP server knows to not lease the subnet ID or subnet broadcast address.)

Reserved (excluded) addresses: The server needs to know which addresses in the subnet to *not* lease. This list allows some addresses to be reserved for assignment as statically assigned IP addresses. For example, most router and switch IP addresses, server addresses, and addresses of most anything other than user devices use a statically assigned IP address. Most of the time, engineers use the same convention for all subnets, either reserving the lowest IP addresses in all subnets, or reserving the highest IP addresses in all subnets.

Default router(s): This is the IP address of the router on that subnet.

DNS IP address(es): This is a list of DNS server IP addresses

Figure 18-4 shows the concept behind the preconfiguration on a DHCP server for two LAN-based subnets, 172.16.1.0/24 and 172.16.2.0/24. The DHCP server sits on the right. For each subnet, the server defines all the items in the list. In this case, the configuration reserves the lowest IP addresses in the subnet to be used as static addresses.

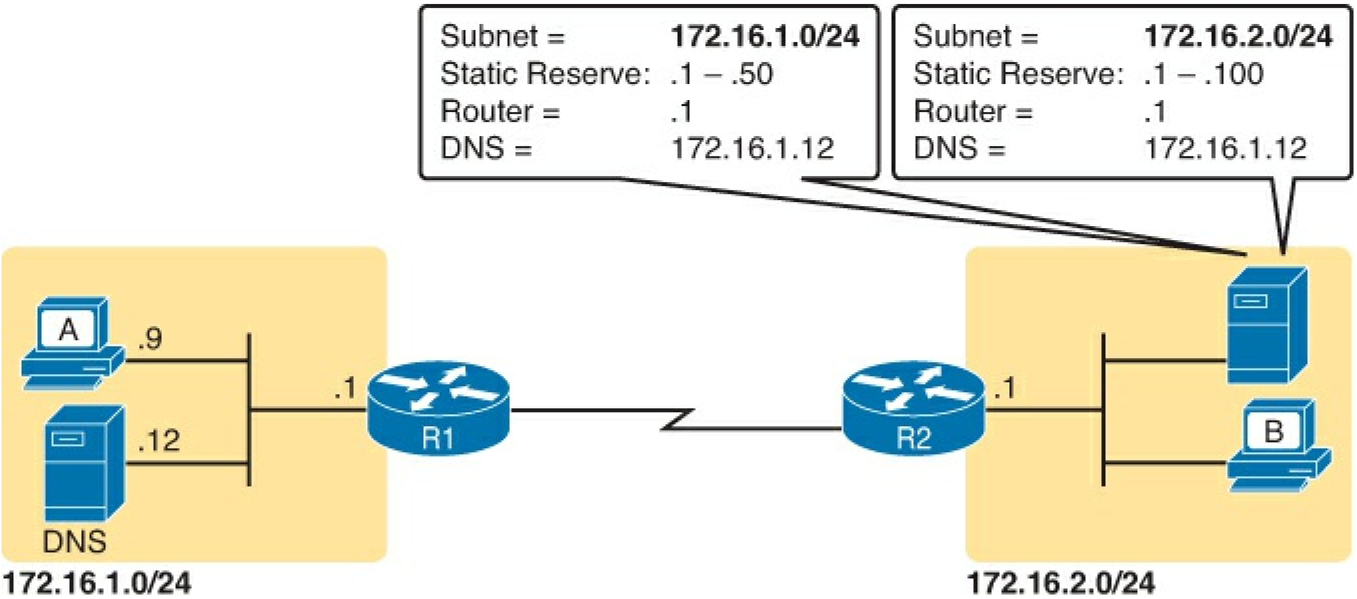


Figure 18-4. Preconfiguration on a DHCP Server

The configuration can list other parameters as well. For example, it can set the time limit for leasing an IP address. The server leases an address for a time (usually a number of days), and then the client can ask to renew the lease. If the client does not renew, the server can reclaim the IP address and put it back in the pool of available IP addresses. The server configuration sets the maximum time for the lease.

DHCP Server Configuration and Verification on Routers

A quick Google search on "DHCP server products" reveals that many companies offer DHCP server software. Cisco routers (and some Cisco switches) can also act as a DHCP server with just a little added configuration. This last topic in DHCP shows how to configure and verify the operation of DHCP on a Cisco router.

IOS DHCP Server Configuration

The previous page or two should have prepared you for the kinds of information that a server needs to configure. The Cisco DHCP server is no different. The configuration groups most of the parameters into a new configuration area, one per subnet, called a *DHCP pool*. The only DHCP command that sits outside the pool is the command that defines the list of addresses excluded from being leased by DHCP.

The Cisco IOS DHCP server configuration steps are as follows:

Key Topic

Step 1. Exclude addresses from being assigned by DHCP: **ip dhcp excluded-address** *first last*

Step 2. Create a DHCP pool and go to pool configuration mode: **ip dhcp pool** *name*

- **A.** Define subnet that the DHCP server should support: **network** *subnet-ID mask* or **network** *subnet-ID prefix-length*
- **B.** Define default router IP address(es) in that subnet: **default-router** *address1 address2*...
- **C.** Define list of DNS server IP addresses: **dns-server** *address1 address2*...
- **D.** Define length of lease, in days, hours, and minutes: **lease** *days hours minutes*
- **E.** Define the DNS domain name: **domain-name** *name*

Of course, an example can help, particularly with so many configuration commands required. Figure 18-5 shows the organization of the configuration, while sticking to pseudocode rather than the specific configuration commands. (Upcoming

Example 18-1 shows a matching configuration.) Note that for each of the two LAN subnets, there is a global command to exclude addresses, and then a group of settings for each of two different DHCP pools.

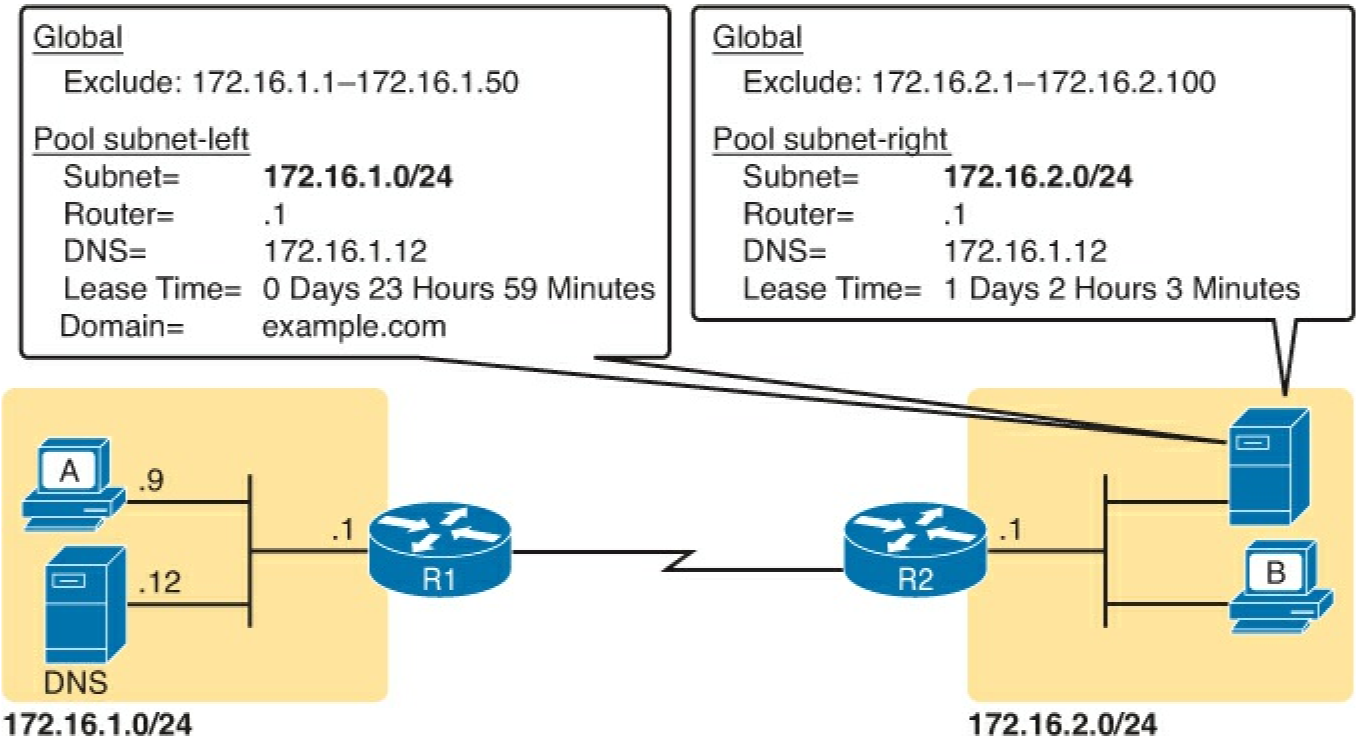

Global
Exclude: 172.16.1.1–172.16.1.50
Pool subnet-left
Subnet= 172.16.1.0/24
Router= .1
DNS= 172.16.1.12
Lease Time= 0 Days 23 Hours 59 Minutes
Domain= example.com
Global
Exclude: 172.16.2.1–172.16.2.100
Pool subnet-right
Subnet= 172.16.2.0/24
Router= .1
DNS= 172.16.1.12
Lease Time= 1 Days 2 Hours 3 Minutes
A
.9
.12
DNS
.1
R1
R2
.1
B
172.16.1.0/24
172.16.2.0/24

Figure 18-5. DHCP Server Configuration Pseudocode

Example 18-1. R2 as a DHCP Server Per the Concepts in Figure 18-5

Click here to view code image

```
ip dhcp excluded-address 172.16.1.1 172.16.1.50
ip dhcp excluded-address 172.16.2.1 172.16.2.100
!
ip dhcp pool subnet-left
network 172.16.1.0 255.255.255.0
dns-server 172.16.1.12
default-router 172.16.1.1
lease 0 23 59
domain-name example.com
!
ip dhcp pool subnet-right
network 172.16.2.0 /24
dns-server 172.16.1.12
default-router 172.16.2.1
lease 1 2 3
```

Focus on subnet 172.16.1.0/24 for a moment: the subnet configured as pool subnet-left. The subnet ID and mask match the subnet ID chosen for that subnet. Then, the global **ip dhcp excluded-address** command, just above, reserves 172.16.1.1 through 172.16.1.50, so that this DHCP server will not lease these addresses. The server will automatically exclude the subnet ID (172.16.1.0) as well, so this DHCP server will begin leasing IP addresses starting with the .51 address.

Finally, note that configuring a router as a DHCP server does not remove the need for the **ip helper-address** command. If DHCP clients still exist on LANs that do not have a DHCP server, then the routers connected to those LANs still need the **ip helper-address** command. For example, in Figure 18-5, R1 would still need the **ip helper-address** command on its LAN interface.

IOS DHCP Server Verification

The IOS DHCP server function has several different **show** commands. These three commands list most of the details:

show ip dhcp binding: Lists state information about each IP address currently leased to a client

show ip dhcp pool [*poolname*]**:** Lists the configured range of IP addresses, plus statistics for the number of currently leased addresses and the high-water mark for leases from each pool

show ip dhcp server statistics: Lists DHCP server statistics

Example 18-2 shows sample output from two of these commands, based on the configuration from Figure 18-5 and Example

18-1. In this case, the DHCP server leased one IP address from each of the pools, one for host A, and one for host B, as seen in the highlighted portions of the output.

Example 18-2. Verifying Current Operation of a Router-Based DHCP Server

Click here to view code image

```
R2# show ip dhcp binding
Bindings from all pools not associated with VRF:
IP address Client-ID/ Lease expiration Type
Hardware address/
User name
172.16.1.51 0063.6973.636f.2d30. Oct 12 2012 02:56 AM Automatic
3230.302e.3131.3131.
2e31.3131.312d.4661.
302f.30
172.16.2.101 0063.6973.636f.2d30. Oct 12 2012 04:59 AM Automatic
3230.302e.3232.3232.
2e32.3232.322d.4769.
302f.30
R2# show ip dhcp pool subnet-right
Pool subnet-right :
Utilization mark (high/low) : 100 / 0
Subnet size (first/next) : 0 / 0
Total addresses : 254
Leased addresses : 1
Pending event : none
1 subnet is currently in the pool :
Current index IP address range Leased addresses
172.16.2.102 172.16.2.1 - 172.16.2.254 1
```

Note that the output in Example 18-2 does not happen to list the excluded addresses, but it does show the affects. The addresses assigned to the clients end with .51 (host A, subnet 172.16.1.0) and .101 (host B, subnet 172.16.2.0), proving that the server did exclude the addresses as shown in the configuration in Example 18-1. The server avoided the .1 through .50 addresses in subnet 172.16.1.0, and the .1 through .100 addresses in subnet 172.16.2.101.

> **Note**
>
> The DHCP server keeps status (state) information about each DHCP client that leases an address. Specifically, it remembers the DHCP client ID, and the IP address leased to the client. As a result, an IPv4 DHCP server can be considered to be a stateful DHCP server. This description will be useful when reading about DHCP for IPv6 in Chapter 28, "Implementing IPv6 Addressing on Hosts."

Detecting Conflicts with Offered Versus Used Addresses

The Cisco IOS DHCP server also looks for potential conflicts between addresses it leases and statically configured addresses. Although the DHCP server configuration clearly lists the addresses in the pool and that to be excluded from the pool, hosts can still statically configure addresses from the range inside the DHCP pool. In other words, no protocols prevent a host from statically configuring and using an IP address from within the range of addresses used by the DHCP server.

Knowing that some host might have statically configured an address from within the range of addresses in the DHCP pool, both DHCP servers and clients try to detect such problems, called conflicts, before the client uses a newly leased address.

DHCP servers detect conflicts by using pings. Before offering a new IP address to a client, the DHCP server first pings the address. If the server receives a response to the ping, some other host must already be using the address, which lets the server know a conflict exists. The server notes that particular address as being in conflict, and the server does not offer the address, moving on to the next address in the pool.

The DHCP client can also detect conflicts, but instead of using ping, it uses ARP. In the client case, when the DHCP client receives from the DHCP server an offer to use a particular IP address, the client sends an ARP for that address. If another host replies, the DHCP client has found a conflict.

Example 18-3 lists output from the router-based DHCP server on R2, after host B detected a conflict using ARP. Behind the scenes, host B used DHCP to request a lease, with the process working normally until host B used ARP and found some other device already used 172.16.2.102. At that point, host B then sent a DHCP message back to the server, rejecting the use of address 172.16.2.102. The example shows the router's log message related to host B's discovery of the conflict, and a **show** command that lists all conflicted addresses.

Example 18-3. Displaying Information About DHCP Conflicts in IOS

Click here to view code image

```
*Oct 16 19:28:59.220: %DHCPD-4-DECLINE_CONFLICT: DHCP address conflict: client
0063.6973.636f.2d30.3230.302e.3034.3034.2e30.3430.342d.4769.302f.30 declined
172.16.2.102.
R2# show ip dhcp conflict
IP address Detection method Detection time VRF
172.16.2.102 Gratuitous ARP Oct 16 2012 07:28 PM
```

The **show ip dhcp conflict** command lists the method through which the server added each address to the conflict list: either gratuitous ARP, as detected by the client, or ping, as detected by the server. The server avoids offering these conflicted addresses to any future clients, until the engineer uses the **clear ip dhcp conflict** command to clear the list.

Verifying Host IPv4 Settings

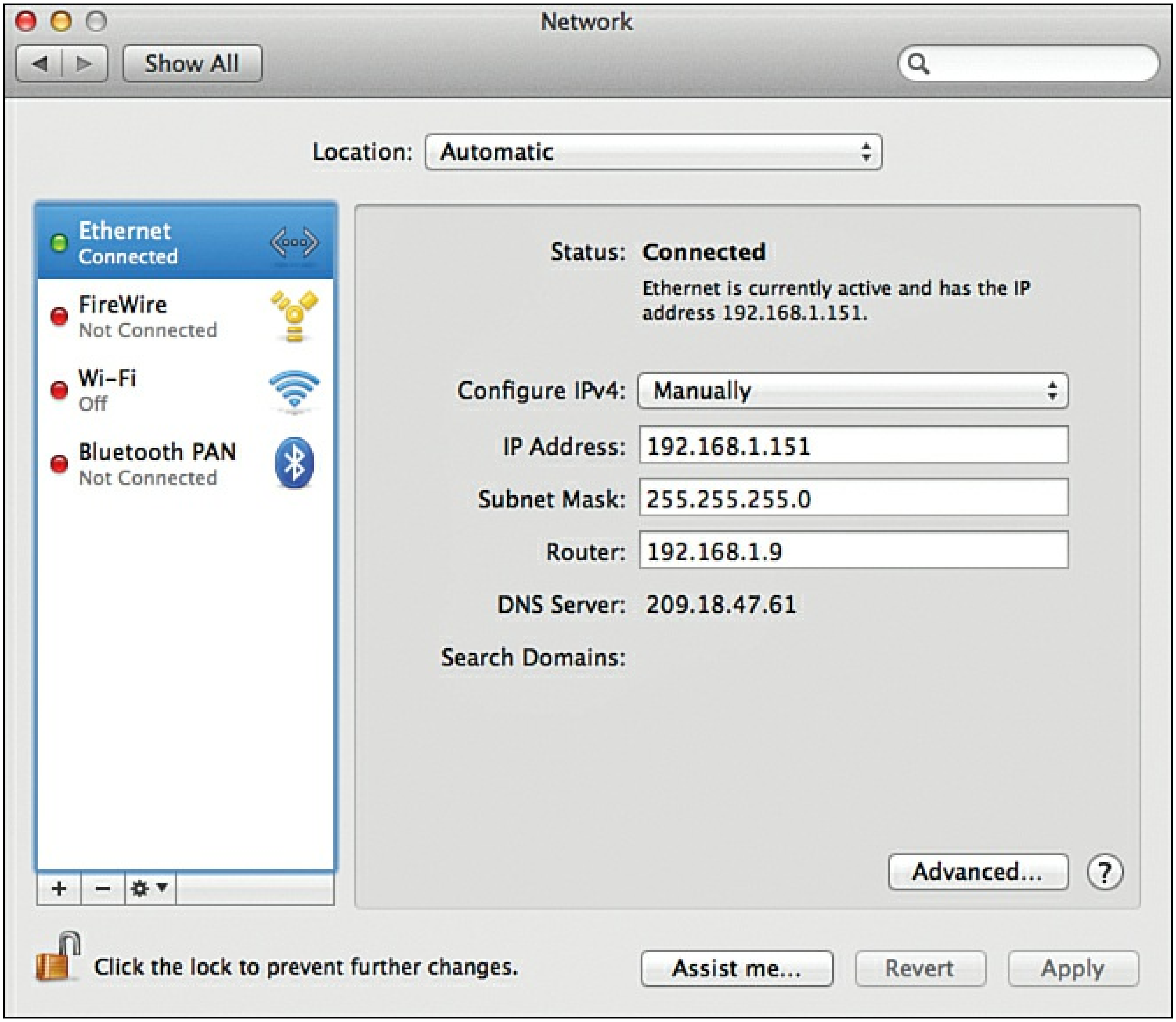
Some hosts use DHCP to learn their IPv4 settings. Others manually set all their settings. Other hosts actually allow you to make some settings manually, and learn other settings with DHCP.

Regardless of how a given host builds its IPv4 configuration, that host will either work, or have problems. And if it has problems, someone needs to be ready and able to jump in and help solve the problem. On hosts, that means someone needs to be able to find the IPv4 settings, make sure they are correct, and troubleshoot problems related to the host IP settings.

This short section brushes the surface of how to verify IPv4 settings on hosts. This section touches on each of the settings, showing some host commands used to confirm each setting, as well as giving a few related hints on how to confirm if it is working or not. Note that the CCNA and ICND2 exams take a closer look at end-to-end troubleshooting.

IP Address and Mask Configuration

Most every OS in the world—certainly the more common OSs people work with every day—have a fairly easy-to-reach window that lists most if not all the IPv4 settings in one place. For example, Figure 18-6 shows the Network configuration screen from a user host OS (Mac OS X in this case), with all the IPv4 settings. This particular example shows the big four settings: address, mask, router, and DNS.



Location: Automatic

Status: Connected

Ethernet is currently active and has the IP address 192.168.1.151.

Configure IPv4: Manually

IP Address: 192.168.1.151

Subnet Mask: 255.255.255.0

Router: 192.168.1.9

DNS Server: 209.18.47.61

Search Domains:

Click the lock to prevent further changes.

Figure 18-6. IP Address, Mask, and Default Router Settings on Mac OS

However, beyond these windows into the graphical user interface (GUI) of any OS, most OSs have a variety of networking commands available from a command line. Interestingly, some of the commands are the same across many different OSs, even between Microsoft Windows versions and other OSs.

For example, to verify the IP address, mask, default router, and other settings, OSs typically support either the **ipconfig** (Windows) or **ifconfig** (Linux and Mac OS) commands. Both commands have several options that can be seen by adding a **-?** to the end. Example 18-4 shows a sample from a Windows PC.

Example 18-4. ipconfig /all **(Windows)**

Click here to view code image

```
C:\DOCUME1\OWNER> ipconfig /all
Windows IP Configuration

Ethernet adapter Wireless Network Connection 3:

Connection-specific DNS Suffix . : Belkin
Description . . . . . . . . . . . : Linksys WUSB600N Dual-Band Wireless-N USB
Network Adapter
Physical Address. . . . . . . . . : 00-1E-E5-D8-CB-E4
Dhcp Enabled. . . . . . . . . . . : Yes
Autoconfiguration Enabled . . . . : Yes
IP Address. . . . . . . . . . . . : 192.168.2.13
Subnet Mask . . . . . . . . . . . : 255.255.255.0
Default Gateway . . . . . . . . . : 192.168.2.1
DHCP Server . . . . . . . . . . . : 192.168.2.1
DNS Servers . . . . . . . . . . . : 192.168.2.1
Lease Obtained. . . . . . . . . . : Wednesday, October 10, 2012 3:25:00AM
Lease Expires . . . . . . . . . . : Monday, January 18, 2013 11:14:07 PM
```

Name Resolution with DNS

The Domain Name System (DNS) defines a protocol as well as a worldwide system of servers that use DNS. While incredibly useful—it might be one of the single most important protocols in the world of TCP/IP—DNS does not require attention from the routers and switches between the user devices and the DNS servers. This short section explains why, but shows you a few router commands related to DNS that might be handy anyway.

Inside a single enterprise, the company uses a couple of redundant DNS servers, each of which can resolve any host names for any hosts inside the company. Figure 18-7 shows an example using a single company, with a client on the left using the DNS server at the top of the figure. Step 1 shows the DNS Request message, asking the DNS server to resolve name “Server1” into its corresponding IP address. The DNS Server sends back a DNS Reply, listing the IP address. Finally, at Step 3, the client can send a packet to 10.1.2.3, the address used by Server1.

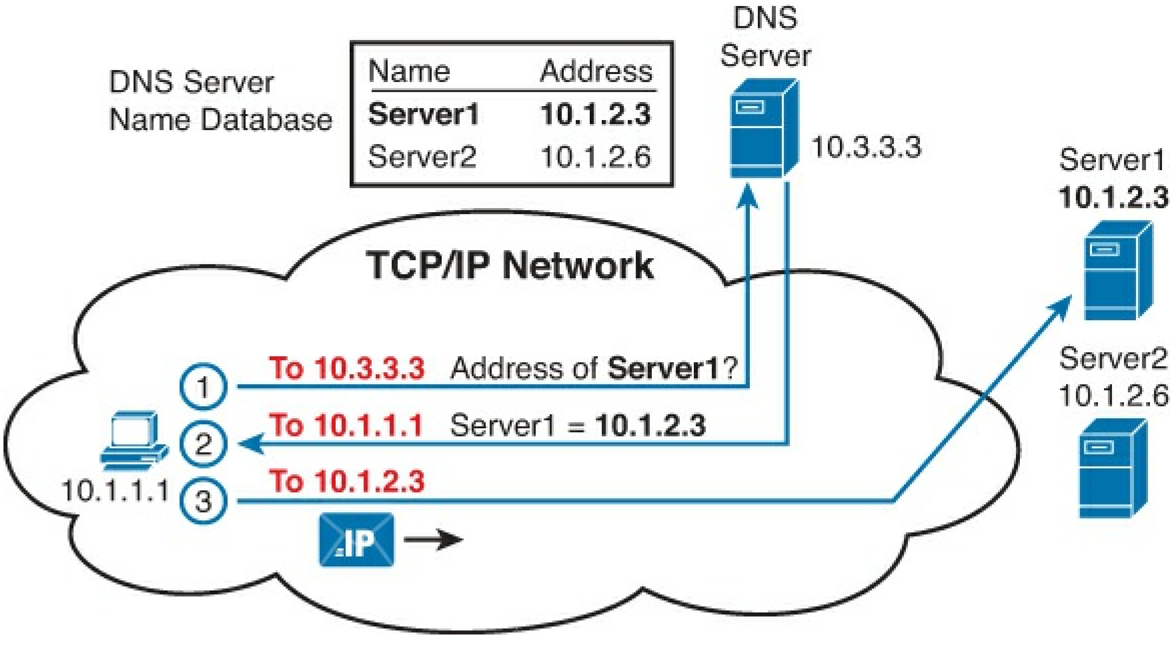


Figure 18-7. Host Resolves Name to IP Address Before Sending Packet to Server1

Now stop for a moment, and focus on the “To:” part of the three messages. Each packet has a known unicast destination address. The routers in the TCP/IP network can simply forward those packets. No need for any special configuration, no need for a command and function like the **ip helper-address** command used with DHCP. In short, the routers and switches have no extra work to do, and no extra configuration required, to support DNS between a host and the DNS servers.

When looking at problems with hosts, you can and should check the DNS settings to find out what DNS server addresses the host tries to use. At the same time, the user at the host can make the host try and use DNS. For example:

- Open a web browser and type in the name of the web server. DNS resolves the name that sits between the // and the first /.
- Use a command like **nslookup** *hostname*, supported on most PC OSs, which sends a DNS Request to the DNS server, showing the results.

Example 18-5 shows an example of the **nslookup** command that confirms that the host's DNS server is set to 209.18.47.61, with the end of the output showing that the DNS request worked.

Example 18-5. nslookup **Command (Mac)**

[Click here to view code image](#)

```
WendellOdoms-iMac: wendellodom$ nslookup www.certskills.com
Server: 209.18.47.61
Address: 209.18.47.61#53

Non-authoritative answer:
www.certskills.com canonical name = certskills.com.
Name: certskills.com
Address: 173.227.251.150
```

And as a brief aside, note that routers and switches do have some settings related to DNS. However, these router and switch DNS settings only allow the router or switch to act as a DNS resolver (client). That is, the router and switch will use DNS messages to ask the DNS server to resolve the name into its matching IP address. The commands to configure how a router or switch will resolves host names into their matching addresses (all global commands) are

ip name-server *server_IP...***:** Configure the IP addresses of up to six DNS servers in this one command.

ip host *name address***:** Statically configure one name and matching IP address, on this one router or switch. The local router/switch only will use this IP address if a command refers to the name.

no ip domain-lookup: Disable the DNS resolver function, so that the router or switch does not attempt to ask a DNS server to resolve names. (The **ip domain-lookup** command, a default setting, enables the router to use a DNS server.)

Default Routers

As discussed in some detail back in Chapter 16, "Configuring IPv4 Addresses and Routes," IPv4 host routing logic reduces to a basic two-part choice. For packets destined for a host in the same subnet, the local host sends the packet directly, ignoring any routers. For packets destined for a host in a different subnet, the local host next sends the packet to its default gateway (also known as the default router), expecting that router to forward the packet.

Interestingly, a couple of simple errors can occur between any LAN-based host and their default router. For a LAN-based host's default router setting to work, the following must be true:

Key Topic

- The host link to the LAN and the default router link to the LAN must be in the same VLAN.
- The host and default router IP addresses must be in the same subnet.
- The host default router setting must refer to the same IP address configured on the router. (In other words, if the host claims the default router is 10.1.1.1, make sure the router interface IP address is not 10.1.1.2.)
- The LAN switches must not discard the frame because of the port security configuration.

All of the above settings and choices can be mismatched between a host and the default router. On the router, the settings can be checked with the usual CLI commands: **show interfaces**, **show ip interface brief**, **show protocols**, and **show running-config**. On the switch, to check the VLAN assignments, use **show interfaces status**, **show vlan**, and **show interfaces switchport**.

On the host, the methods to check the default router setting of course differ depending on the OS. A look at the settings using the GUI simply lists the default router. However, common command on most user host OSs is the **netstat -rn** command, which lists the default gateway as the route for destination 0.0.0.0. Example 18-6 shows an example **netstat -rn** command from a PC running windows, with the default router setting highlighted.

Example 18-6. netstat -rn **Command (Windows)**

[Click here to view code image](#)

```
C:\DOCUME1\OWNER> netstat -rn
Interface List
0x1 ........................... MS TCP Loopback interface
0x2 ...00 11 2f 16 c4 7a ...... NVIDIA nForce Networking Controller - Packet Scheduler
Miniport
0x3 ...00 1e e5 d8 cb e4 ...... Linksys WUSB600N Dual-Band Wireless-N USB Network
Adapter - Packet Scheduler Miniport
===========================================================================
===========================================================================
Active Routes:
Network Destination Netmask Gateway Interface Metric
```

```
0.0.0.0 0.0.0.0 192.168.2.1 192.168.2.13 25
127.0.0.0 255.0.0.0 127.0.0.1 127.0.0.1 1
169.254.0.0 255.255.0.0 192.168.2.13 192.168.2.13 20
192.168.2.0 255.255.255.0 192.168.2.13 192.168.2.13 25
192.168.2.13 255.255.255.255 127.0.0.1 127.0.0.1 25
192.168.2.255 255.255.255.255 192.168.2.13 192.168.2.13 25
224.0.0.0 240.0.0.0 192.168.2.13 192.168.2.13 25
255.255.255.255 255.255.255.255 192.168.2.13 2 1
255.255.255.255 255.255.255.255 192.168.2.13 192.168.2.13 1
Default Gateway: 192.168.2.1
==========================================================================
```

Another good step to take to verify the default router is to find out if ARP works for the default router. For example, host A in Figure 18-8, when sending packets to host D, in the same subnet, will send the packet directly to host D. So, host A will first need an ARP entry for host D. Similarly, before sending a packet to server B, which sits on another subnet, host A will need an ARP entry for R1's MAC address.

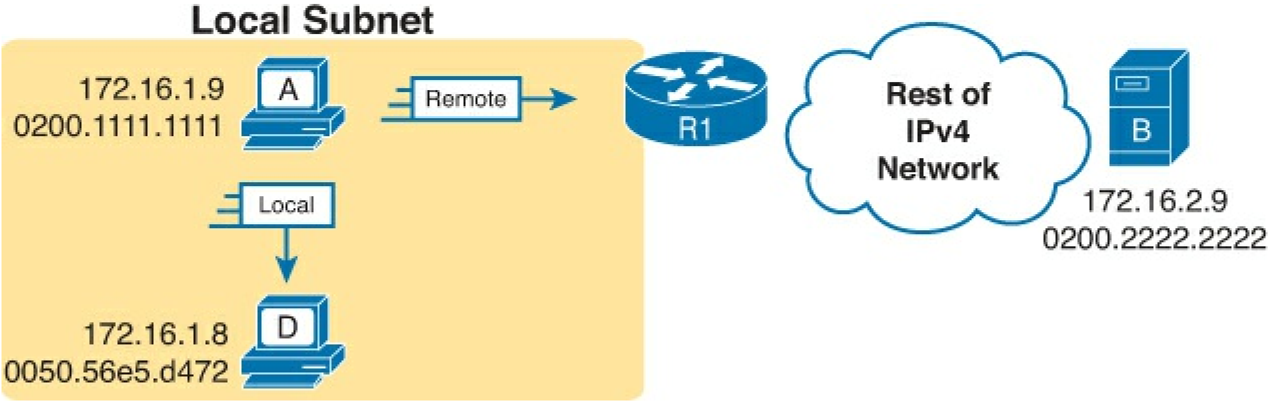


Figure 18-8. Host IP and MAC Addresses in the Next Two ARP Examples

The **arp -a** command happens to be another common command on many user OSs. listing the host's ARP table. The same in Example 18-7 shows host A's ARP table after host A successful sent a packet to both server B and host D. Note that server B's IP address of 172.16.2.9 is not listed, because the ARP table lists IP addresses for IP addresses on the same subnet, and not those on remote subnets.

Example 18-7. ARP Table on Host A (Windows)

Click here to view code image

```
C:\Users\wodom> arp -a

Interface: 172.16.1.9 --- 0xa
Internet Address Physical Address Type
172.16.1.1 02-00-01-01-01-01 dynamic
172.16.1.8 00-50-56-e5-d4-72 dynamic
```

Routers also need to keep an ARP table, so they can encapsulate IP packets into LAN frames. Example 18-8 shows the output of the **show arp** command on Router R1, which lists an entry for host A (172.16.1.9), and for the router itself (172.16.1.1). (Note that hosts typically do not list their own IP addresses in their own ARP cache, but the Cisco router ARP cache does.)

Example 18-8. ARP Table on Router R1

Click here to view code image

```
R1# show arp
Protocol Address Age (min) Hardware Addr Type Interface
Internet 172.16.1.1 - 0200.0101.0101 ARPA GigabitEthernet0/0
Internet 172.16.1.9 2 0200.1111.1111 ARPA GigabitEthernet0/0
```

Testing Connectivity with ping, traceroute, and telnet

While checking a host's IPv4 settings can be important, the final true test for hosts is whether the host applications can communicate like they should. Can the user open a web browser and connect to web sites? Does email work? Can all those apps on a smart phone connect through the Internet?

This last section of the chapter looks at some connectivity testing tools that ask a simpler but cleaner question: Can a host send packets to another host, and can that host send packets back? The user applications cannot work until the two hosts can send packets back and forth. If the tools show that IPv4 packets can indeed flow from between two hosts, but an application does not work, then the troubleshooting process can next look at why the application might be having problems. However, if the hosts cannot send packets to each other, the troubleshooting process points to some network problem that prevents the packets from being forwarded correctly.

Specifically, this section looks at the **ping** and **traceroute** commands. **ping** answers the basic question of whether two hosts can send packets back and forth to each other or not. **traceroute** takes a more diagnostic approach, so that if the hosts cannot send packets, this command helps a network engineer determine where the problem is occurring.

This section ends with some details about how to use Telnet to move around between Cisco routers so that network engineers can make better use of commands like **ping** and **traceroute**.

The ping Command

The **ping** command exists to test connectivity. It sends a series of packets to one destination IP address. The packets mean basically "if you get this packet, send a reply back." Each time the sender sends the request, and the other host sends a reply, the **ping** command knows a packet made it from the source host, to the destination, and back.

More formally, the **ping** command uses the Internet Control Message Protocol (ICMP), specifically the ICMP Echo Request and ICMP Echo Reply messages. ICMP defines many other messages as well, but these two messages were made specifically for connectivity testing by commands like **ping**. As a protocol, ICMP does not rely on a transport layer protocol like TCP or UDP, and it does not use any application layer protocol. It exists to assist IP by helping manage the IP network functions.

Figure 18-9 shows the ICMP messages, with IP headers, in an example. In this case, the user at host A opens a command prompt and issues the **ping 172.16.2.101** command, testing connectivity to host B. The command sends one Echo Request, and waits (Step 1); host B receives the messages, and sends back an Echo Reply (Step 2). At that point, the ping command can issue a message to the user, confirming that the ping worked.

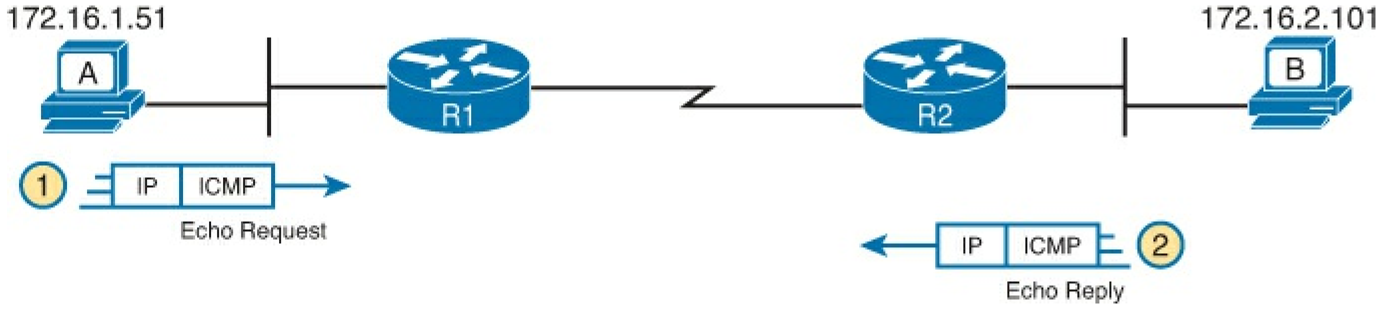


Figure 18-9. Concept Behind *ping 172.16.2.101* on Host A

The **ping** command is supported on many different devices and many common OSs. The command has many options: the name or IP address of the destination, how many times the command should send an Echo Request, how long it should wait (timeout) for an Echo Reply, how big to make the packets, and many others. Example 18-9 shows a sample from host A, with the same command that matches the concept in Figure 18-9: a **ping 172.16.2.101** command on host A.

Example 18-9. Sample Output from Host A's ping 172.16.2.101 **Command**

Click here to view code image

```
WendellOdoms-iMac: wendellodom$ ping 172.16.2.101
PING 172.16.2.101 (172.16.2.101): 56 data bytes
64 bytes from 172.16.2.101: icmp_seq=0 ttl=64 time=1.112 ms
64 bytes from 172.16.2.101: icmp_seq=1 ttl=64 time=0.673 ms
64 bytes from 172.16.2.101: icmp_seq=2 ttl=64 time=0.631 ms
64 bytes from 172.16.2.101: icmp_seq=3 ttl=64 time=0.674 ms
64 bytes from 172.16.2.101: icmp_seq=4 ttl=64 time=0.642 ms
64 bytes from 172.16.2.101: icmp_seq=5 ttl=64 time=0.656 ms
^C
--- 172.16.2.101 ping statistics ---
6 packets transmitted, 6 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 0.631/0.731/1.112/0.171 ms
```

Testing IP Routes with ping on a Router

Today, many tools exist so that support personnel can view and take over the desktop GUI of a remote user device. Customer support representatives (CSR) can sit at their desks in one city, receive a phone call from a customer, and connect to look at the user's desktop GUI in a matter of a few clicks—as long as the problem is not a network problem. However, if a network problem exists, the remote connection to the user's device can fail, and the CSR has to troubleshoot the IP connectivity problem without access to the user device.

In some cases, talking a user through typing the right commands and making the right clicks on their machines can be a problem. Or, the user just might not be available. In those cases, the CSR could connect to a nearby router (with Telnet or SSH) and use the router **ping** command to test the host connectivity.

For example, in Figure 18-9, imagine that the user of host A had called IT support with a problem related to sending packets to host B (in Figure 18-9). The CSR tries, but fails, to remotely connect to host A's desktop. So, the CSR Telnets to Router R1, the router nearest to host A, and pings host B from there, as seen in Example 18-10.

Example 18-10. Router R2 Pings Host B (Two Commands)

Click here to view code image

```
R1# ping 172.16.2.101
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.101, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 1/2/4 ms
R1# ping 172.16.2.101
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.101, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/2/4 ms
```

Focus on the first command for a moment. The Cisco IOS **ping** command sends five Echo messages, with a timeout of 2 seconds. If the command does not receive an Echo Reply within two seconds, the command considers that message to be a failure, and it sends the next one. So each **ping** command, when getting no responses at all, takes about 10 seconds to complete. The command lists a period for each unanswered Echo Request, while success—the arrival of an Echo Reply within two seconds—shows up as an exclamation point. In this case, the first one failed, and the others worked.

Interestingly, the two **ping** commands in the sample show a common occurrence: the first **ping** command shows failures for a few messages, but then the rest of the messages work. This usually happens because some device in the end-to-end route is missing an ARP table entry, and must first complete the ARP process before being ready to forward the packet. (For this test, I first used the **clear ip arp 172.16.2.101** command on R2 to clear its ARP cache, so that the test would show at least one failure.)

Controlling the Source IP Address with Extended ping

The **ping** command on Router R1 in Example 18-10 tests many parts of the connectivity from host A to host B, but not all. In fact it has a subtle problem in what this command actually tests. Thankfully, the IOS **ping** command allows us to overcome the problem using a function called an extended ping.

First, to see the problem—or really a missed opportunity—consider again the **ping 172.16.2.101** command on Router R1, as shown in Example 18-10. The command does confirm that many parts of the network works correctly. It clearly tests the physical and data link functions between R1 and R2, as well as between R2 and host B. It tests the network layer routes towards 172.16.2.101 (the forward route). However, the not-so-obvious problem is that it does not test the reverse route towards host A.

The **ping** in Example 18-9 does not properly test the reverse route back toward host A because of how the router chooses the source IP address for the **ping** command's packets. Figure 18-10 shows the default behavior of the router **ping** command. It has to pick a source IP address to use for the Echo Request, and routers choose the *IP address of the outgoing interface*. The Echo Request, from R1 to host B, flows with source IP address 172.16.4.1 (R1's S0/0/0 IP address), and of course destination IP address 172.16.2.101.

Key Topic

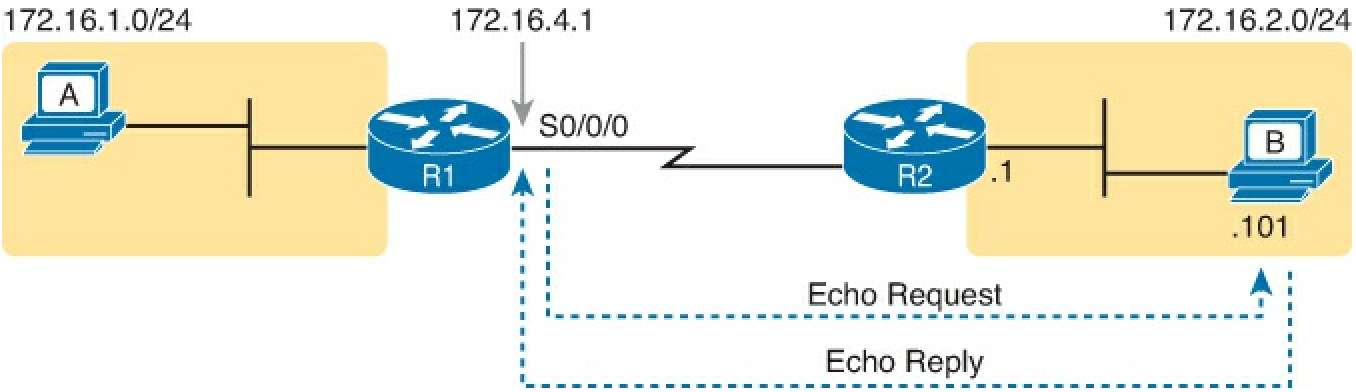


Figure 18-10. Standard *ping 172.6.2.101* Command Using the Source Interface IP Address

The ICMP Echo Reply packet shows the missed opportunity. It flows to an IP address in subnet 172.16.4.0/24, and not to an IP address in host A's subnet of 172.16.1.0/24. So, the ICMP Echo Reply does not test the route back to host A's subnet. A better test would be to use R1's LAN IP address as the source of the Echo Request, so that the Echo Reply messages would flow back to host A's subnet, testing routes to that subnet, as shown in Figure 18-11.

Key Topic

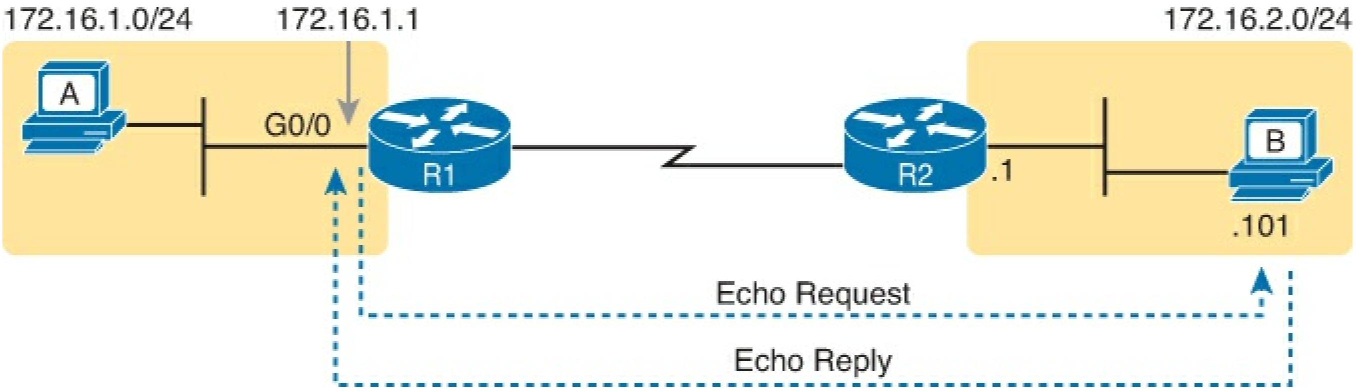


Figure 18-11. Extended *ping* Command Using the LAN as Source Interface IP Address

The router extended **ping** command allows the user to choose from several additional parameters on the **ping** command as compared to the standard **ping** command. As you would guess by now, this command does let the user choose the source IP address as any of the local router's own IP addresses. The command can refer to the IP address directly, or to the router interface.

While the extended **ping** command allows the user to type all the parameters on a potentially long command, it also allows users to simply issue the **ping** command, press Enter, with IOS then asking the user to answer questions to complete the command, as shown in Example 18-11. The example shows the **ping** command on R1 that matches the logic in Figure 18-11.

Example 18-11. Creating a Better Test Using the Extended ping **Command**

Click here to view code image

```
R1# ping
Protocol [ip]:
Target IP address: 172.16.2.101
Repeat count [5]:
Datagram size [100]:
Timeout in seconds [2]:
Extended commands [n]: y
Source address or interface: 172.16.1.1
Type of service [0]:
Set DF bit in IP header? [no]:
Validate reply data? [no]:
Data pattern [0xABCD]:
Loose, Strict, Record, Timestamp, Verbose[none]:
Sweep range of sizes [n]:
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.101, timeout is 2 seconds:
Packet sent with a source address of 172.16.1.1
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/2/4 ms
```

Reading from the top down, the first two highlighted lines show where the extended ping options start. If the user had answered "n" or "no" on the "Extended commands" option, IOS would not have asked the remaining questions for the extended version of the command. By answering yes, IOS asks the extra questions, including the "Source address or interface" question used to supply 172.16.1.1 as the source IP address in this case.

The last highlighted line confirms the source IP address used for this test. Note that IOS only lists this line of output when the extended ping command happens to specify the source IP address to use.

Note

The extended **ping** command does allow you to refer to the interface, but it must be the full spelled-out interface name, for example, gigabitethernet0/0.

The extended version of the **ping** command, using the source interface option, creates a much more realistic connectivity test. Comparing the standard and extended **ping** examples in this section, both do the same job in testing connectivity and links from R1 toward host B. However, the extended **ping** tests the likely route back to the user host (host A), while the standard ping does not.

The traceroute Command

Imagine some network engineer or CSR starts to troubleshoot some problem. They ping from the user's host, ping from a nearby router, and after a few commands, convince themselves that the host can indeed send and receive IP packets. The problem might not be solved yet, but the problem does not appear to be a problem with packet delivery between the user's device and the rest of the network.

Now imagine the next problem comes along, and for that devices, pings fail. It appears that some problem does exist in the IP network. Where is the problem? Where should the engineer look more closely? While **ping** can be helpful in answering these questions, isolating the source of the problem, the **traceroute** command might be a better option. The **traceroute** command systematically helps pinpoint problems by showing how far a packet goes through an IP network before being discarded.

The **traceroute** command that fully completes identifies the routers in the path from source host to destination host. Specifically, it lists the next-hop IP address of each router that would be in each of the individual routes. For example, a **traceroute 172.16.2.101** command on host A in Figure 18-12 would identify an IP address on Router R1, another on Router R2, and then host B, as shown in the figure. Example 18-12 that follows lists the output of the command, taken from host A.

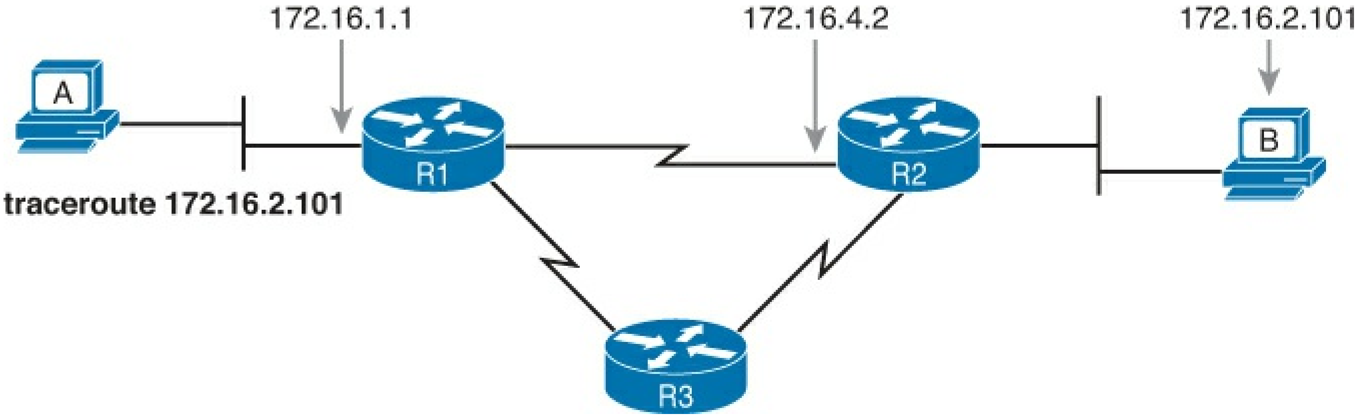


Figure 18-12. IP Addresses Identified by a Successful *traceroute 172.16.2.101* Command on Host A

Example 18-12. Example Output from traceroute 172.16.2.101 **on Host A**

Click here to view code image

```
WendellOdoms-iMac: wendellodom$ traceroute 172.16.2.101
traceroute to 172.16.2.101, 64 hops max, 52 byte packets
1 172.16.1.1 (172.16.1.1) 0.870 ms 0.520 ms 0.496 ms
2 172.16.4.2 (172.16.4.2) 8.263 ms 7.518 ms 9.319 ms
3 172.16.2.101 (172.16.2.101) 16.770 ms 9.819 ms 9.830 ms
```

How the traceroute Command Works

The **traceroute** command gathers this information about each router by relying on an ICMP message that was originally meant for other purposes: The ICMP Time-to-Live Exceeded (TTL Exceeded) message.

Before discussing traceroute, you need a little background on TTL and the TTL Exceeded message. In an IP network, the routers can create a loop. A routing loop is something to be avoided, because the routers keep forwarding packets around and around, never delivering them to the correct destination. For example, R1 sends the packet to R2, which sends it to R3, which sends it to R1 again, over and over again, with the same packets going around and around between these three routers.

IPv4 routers deal with one bad side effect of routing loops—the fact that packets keep looping around the network—by discarding looping IP packets. To do so, the IPv4 header holds a field called Time To Live (TTL). The original host sets this value. Then, each router that forwards the packet decrements the TTL value by 1. When a router decrements the TTL to 0, the router perceives the packet is looping around, and the router discards the packet. The router also notifies the host that sent the discarded packet by sending an ICMP TTL Exceeded message.

Now back to **traceroute**. **traceroute** sends messages to make the routers send back a TTL exceeded message, but without a routing loop existing in the network. As a result, the **traceroute** command can identify the router based on the source IP address of the packet holding the ICMP TTL exceeded message.

Specifically, a **traceroute** command begins by sending several packets (usually 3), each with the header TTL field equal to 1. When that packet arrives at the next router—host A's default Router R1 in this example—the router decrements TTL to 0, and discards the packet. The router then sends host A the TTL Exceeded message, which identifies the router's IP address to the **traceroute** command. Figure 18-13 shows one such packet and TTL Exceeded message.

Key Topic

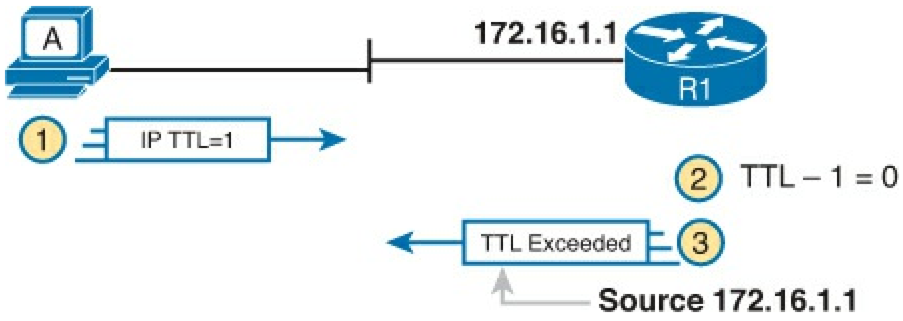


Figure 18-13. How *traceroute* Identifies the First Router in the Route

The **traceroute** command sends several TTL=1 packets, checking them to see if the TTL Exceeded messages flow from the same router, based on the source IP address of the TTL Exceeded message. Assuming the messages come from the same router, the **traceroute** command lists that IP address as the next line of output on the command. Routers have a choice of IP addresses to use, but as you might guess at this point, routers use the IP address of the outgoing interface. In this case, R1's outgoing interface for the message is 172.16.1.1.

To find all the routers in the path, and finally confirm that packets flow all the way to the destination host, the **traceroute** command sends packets with TTL=2, then 3, 4, and so on, until the destination host actually replies. Figure 18-14 shows the first packet with TTL=2, to show how R1 actually forwards the packet, while R2 decrements the TTL to 0, causing R2 to send a TTL Exceeded message being sent back to host A.

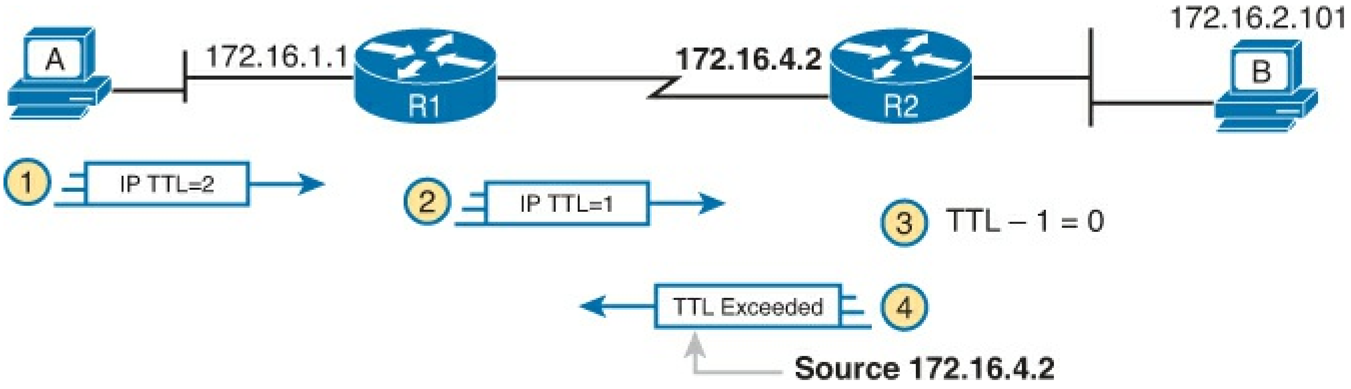


Figure 18-14. TTL=2 Message Sent by *traceroute*

The figure shows these four steps:

Step 1. The **traceroute** command sends a packet, with TTL=2.

Step 2. Router R1 processes the packet, and decrements TTL to 1. R1 forwards the packet.

Step 3. Router R2 processes the packet, and decrements TTL to 0. R2 discards the packet.

Step 4. R2 notifies the sending host of the discarded packet by sending a TTL Exceeded ICMP message. The source IP address of that message is R2's outgoing interface for the message, in this case, 172.16.4.2.

If the **traceroute** command completes, listing the destination host's IP address on a final line, great! In that case, the command has confirmed that connectivity exists from source to destination and back. However, if an IP routing problem exists, the command might either keep running until the user cancels it, or the command finishes but lists codes meaning that the command failed at that point.

When the **traceroute** command cannot complete, or it fails, the last few lines of output tell us where to spend time troubleshooting. When that happens, the problem most likely exists either in the last router listed in the **traceroute** output, or in the next router that should be listed in the output.

For example, if the earlier **traceroute 172.16.2.101** command listed R1 (172.16.1.1), but no other routers, the next troubleshooting steps should happen at R1 and R2. In a large network, narrowing down a problem to a couple of routers can be a great early step to troubleshoot a routing problem.

traceroute **and Similar Commands**

Both the **ping** and **traceroute** commands exist on most OSs, including Cisco IOS. However, some OSs use a slightly different syntax for **traceroute**. For example, most Windows OSs support **tracert** and **pathping**, and not **traceroute**. Linux and MAC OS X support the **traceroute** command.

Cisco IOS supports the **traceroute** command, with the memorable abbreviation **trace**. Like **ping**, **traceroute** can be issued with all parameters on one command line, or by letting IOS prompt the user to answer questions. And like the extended **ping** command, an extended **traceroute** command exists, allowing the network engineer to choose the source IP address, for the same good reasons as done with the **ping** command.

Example 18-13 lists the output of two **traceroute** commands on Router R1. The first, a standard **traceroute** command, uses the default source interface as chosen by R1. The second uses the prompting method by IOS, and shows the user choosing a different source IP address (172.16.1.1).

Example 18-13. Example Standard and Extended traceroute **on R1**

Click here to view code image

```
R1# traceroute 172.16.2.101
Type escape sequence to abort.
Tracing the route to 172.16.2.101
VRF info: (vrf in name/id, vrf out name/id)
1 172.16.4.2 0 msec 0 msec 0 msec
2 172.16.2.101 0 msec 0 msec *

R1# traceroute
Protocol [ip]:
Target IP address: 172.16.2.101
Source address: 172.16.1.1
Numeric display [n]:
Timeout in seconds [3]:
Probe count [3]:
Minimum Time to Live [1]:
Maximum Time to Live [30]:
Port Number [33434]:
Loose, Strict, Record, Timestamp, Verbose[none]:
Type escape sequence to abort.
Tracing the route to 172.16.2.101
VRF info: (vrf in name/id, vrf out name/id)
1 172.16.4.2 0 msec 0 msec 0 msec
2 172.16.2.101 0 msec 0 msec *
```

Note

Host OS **traceroute** commands typically create ICMP Echo Requests. The Cisco IOS **traceroute** command instead creates IP packets with a UDP header. This bit of information might seem trivial at this point. However, when learning about IP access control lists (ACL), note that an ACL can actually filter the traffic from a host's **traceroute** messages, but not the router **traceroute** command, or vice versa.

Telnet and Suspend

Many engineers troubleshoot network problems sitting at their desks. To get access to a router or switch, the engineer just needs to use Telnet or SSH on their desktop PC to connect to each router or switch, often opening multiple Telnet or SSH windows to connect to multiple devices.

As an alternative, the engineer could connect to one router or switch using a Telnet or SSH client on their desktop computer, and then use the **telnet** or **ssh** Cisco IOS EXEC commands to connect to other routers and switches. These commands act as a Telnet or SSH client, respectively, so that you can easily connect to other devices when troubleshooting. When finished, the user could just use the **exit** command to disconnect the Telnet or SSH session.

One of the most important advantages of using the Cisco IOS **telnet** and **ssh** commands is the suspend feature. The suspend feature allows a Telnet or SSH connection to remain active while creating another Telnet or SSH connection, so that you can make many concurrent connections, and then easily switch between the connections. Figure 18-15 shows a sample internetwork with which the text will demonstrate the suspend feature and its power.

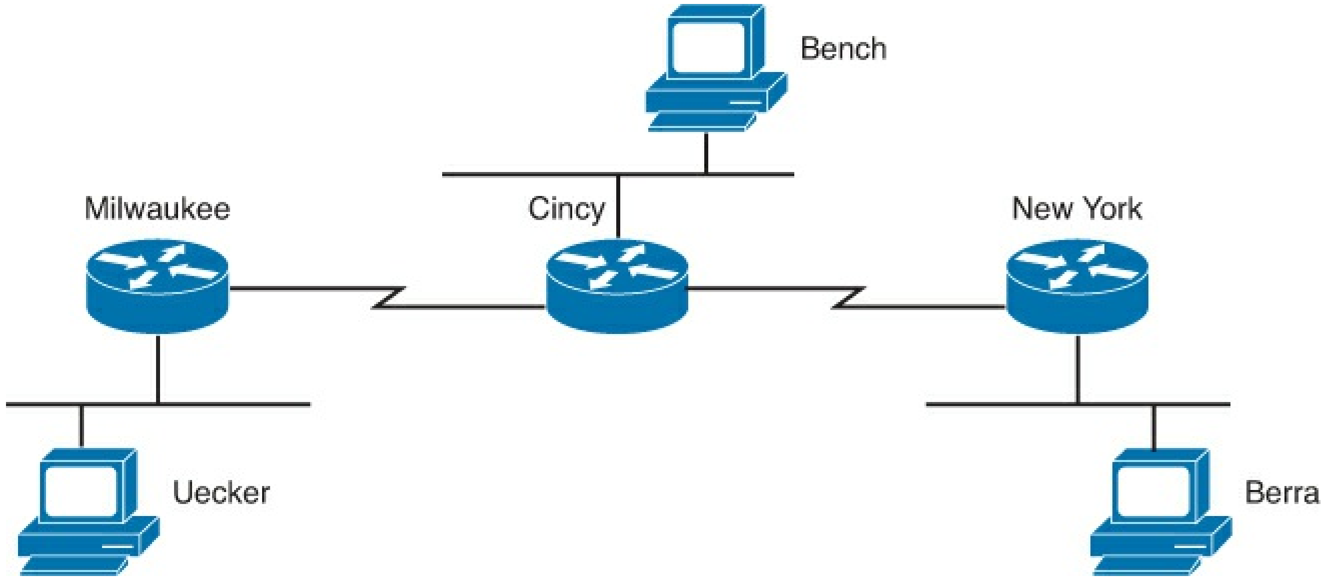


Figure 18-15. Telnet Suspension

The router administrator is using the PC named Bench to telnet into the Cincy router. When connected to the Cincy CLI, the user telnets to router Milwaukee. When in Milwaukee, the user suspends the Telnet session by pressing Ctrl-Shift-6, followed by pressing the letter x. (Note that Ctrl-Shift-6 sends a break character and some international keyboards might map a different key sequence to send a break character.) The user then telnets from the Cincy CLI to New York and again suspends the connection. At the end of the example, the user is concurrently connected to all three routers in one window, with the ability to switch between the connections with just a few keystrokes. Example 18-14 shows example output, with annotations to the side.

Example 18-14. Telnet Suspensions

Click here to view code image

```
Cincy# telnet milwaukee (User issues command to Telnet to Milwaukee)
Trying Milwaukee (10.1.4.252)... Open


User Access Verification

Password: (User plugs in password, can type commands at Milwaukee)
Milwaukee>
Milwaukee>
Milwaukee>
(Note: User pressed Ctrl-Shift-6 and then x)
Cincy# telnet NewYork (User back at Cincy because Telnet was suspended)
Trying NewYork (10.1.6.253)... Open
(User is getting into New York now, based on telnet NewYork command)


User Access Verification


Password:
NewYork> (User can now type commands on New York)
NewYork>
NewYork>
NewYork>
(Note: User pressed Ctrl-Shift-6 and then x)
(Note: User is now back at router Cincy as a result)
Cincy# show sessions (This command lists suspended Telnet sessions)
Conn Host Address Byte Idle Conn Name
1 Milwaukee 10.1.4.252 0 0 Milwaukee
* 2 NewYork 10.1.6.253 0 0 NewYork

Cincy# where (where does the same thing as show sessions)
Conn Host Address Byte Idle Conn Name
1 Milwaukee 10.1.4.252 0 0 Milwaukee
* 2 NewYork 10.1.6.253 0 0 NewYork
```

```
Cincy# resume 1 (Resume connection 1 (see show session) to Milwaukee)
[Resuming connection 1 to milwaukee ... ]

Milwaukee> (User can type commands on Milwaukee)
Milwaukee>
Milwaukee>
! (Note: User pressed Ctrl-Shift-6 and then x, because the user wants to
! go back to Cincy)

Cincy# (WOW! User just pressed Enter and resumes the last Telnet)
[Resuming connection 1 to milwaukee ... ]

Milwaukee>
Milwaukee>
Milwaukee>
(Note: User pressed Ctrl-Shift-6 and then x)
(Note: User is now back at router Cincy as a result)
Cincy# disconnect 1 (No more need to use Milwaukee Telnet terminated!)
Closing connection to milwaukee [confirm] (User presses Enter to confirm)
Cincy#
[Resuming connection 2 to NewYork ... ]
(Pressing Enter resumes most recently suspended active Telnet)

NewYork>
NewYork>
NewYork>
(Note: User pressed Ctrl-Shift-6 and then x)
(Note: User is now back at router Cincy as a result)
Cincy# disconnect 2 (Done with New York, terminate Telnet)
Closing connection to NewYork [confirm] (Just press Enter to confirm)
Cincy#
```

The play-by-play notes in the example explain most of the details. Example 18-14 begins with the Cincy command prompt that would be seen in the Telnet window from host Bench. After telnetting to Milwaukee, the Telnet connection was suspended because the user pressed Ctrl-Shift-6, let go, and then pressed x and let go. Then, after establishing a Telnet connection to New York, that connection was suspended with the same key sequence.

The two connections can be suspended or resumed easily. The **resume** command can be used to resume any suspended connection. To reconnect to a particular session, the **resume** command can list a connection ID, which is shown in the **show sessions** command. (The **where** command provides the same output.) If the **resume** command is used without a connection ID, the command reconnects the user to the most recently suspended connection. Also, instead of using the **resume** command, you can just use the session number as a command. For example, just typing the command **2** does the same thing as typing the command **resume 2**.

The interesting and potentially dangerous nuance here is that if a Telnet session is suspended and you simply press Enter, Cisco IOS Software resumes the connection to the most recently suspended Telnet connection. That is fine, until you realize that you tend to press the Enter key occasionally to clear some of the clutter from the screen. With a suspended Telnet connection, pressing Enter a few times to unclutter the screen reconnects to another router. This is particularly dangerous when you are changing the configuration or using potentially damaging EXEC commands, so be careful about what router you are actually using when you have suspended Telnet connections.

If you want to know which session has been suspended most recently, look for the session listed in the **show sessions** command that has an asterisk (*) to the left of the entry. The asterisk marks the most recently suspended session.

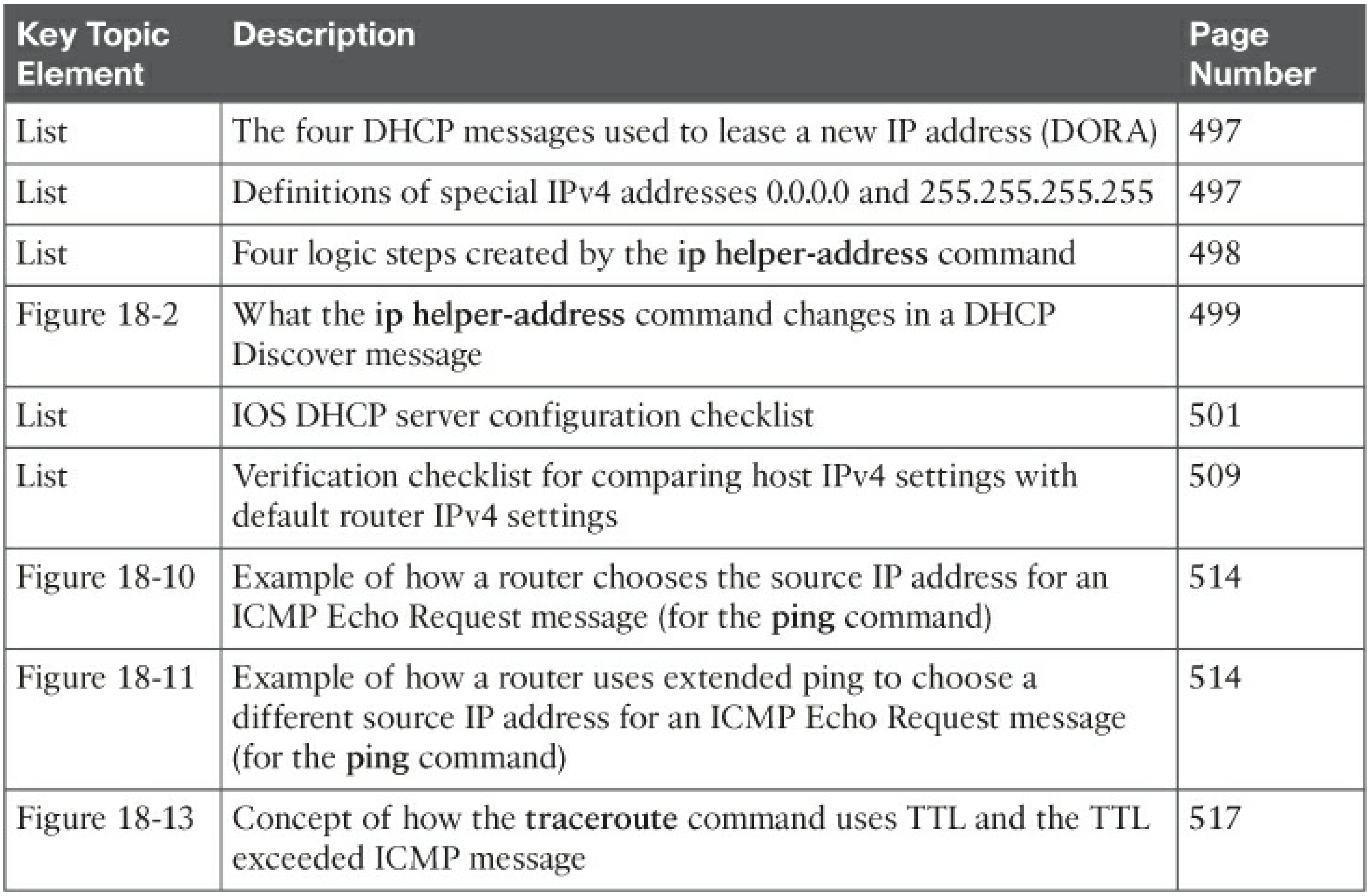
In addition to the commands in Example 18-14 that show how to suspend and resume Telnet and SSH connections, two other commands can list useful information about sessions for users logged into a router. The **show users** command lists all users logged in to the router on which the command is used. This command lists all sessions, including users at the console, and those connecting using both Telnet and SSH. The **show ssh** command lists the same kind of information, but only for users that connected using SSH. Note that these commands differ from the **show sessions** command, which lists suspended Telnet/SSH sessions from the local router to other devices.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 18-2 lists these key topics and where each is discussed.

Table 18-2. Key Topics for Chapter 18



Key Topic Element	Description	Page Number
List	The four DHCP messages used to lease a new IP address (DORA)	497
List	Definitions of special IPv4 addresses 0.0.0.0 and 255.255.255.255	497
List	Four logic steps created by the **ip helper-address** command	498
Figure 18-2	What the **ip helper-address** command changes in a DHCP Discover message	499
List	IOS DHCP server configuration checklist	501
List	Verification checklist for comparing host IPv4 settings with default router IPv4 settings	509
Figure 18-10	Example of how a router chooses the source IP address for an ICMP Echo Request message (for the **ping** command)	514
Figure 18-11	Example of how a router uses extended ping to choose a different source IP address for an ICMP Echo Request message (for the **ping** command)	514
Figure 18-13	Concept of how the **traceroute** command uses TTL and the TTL exceeded ICMP message	517

Definitions of Key Terms

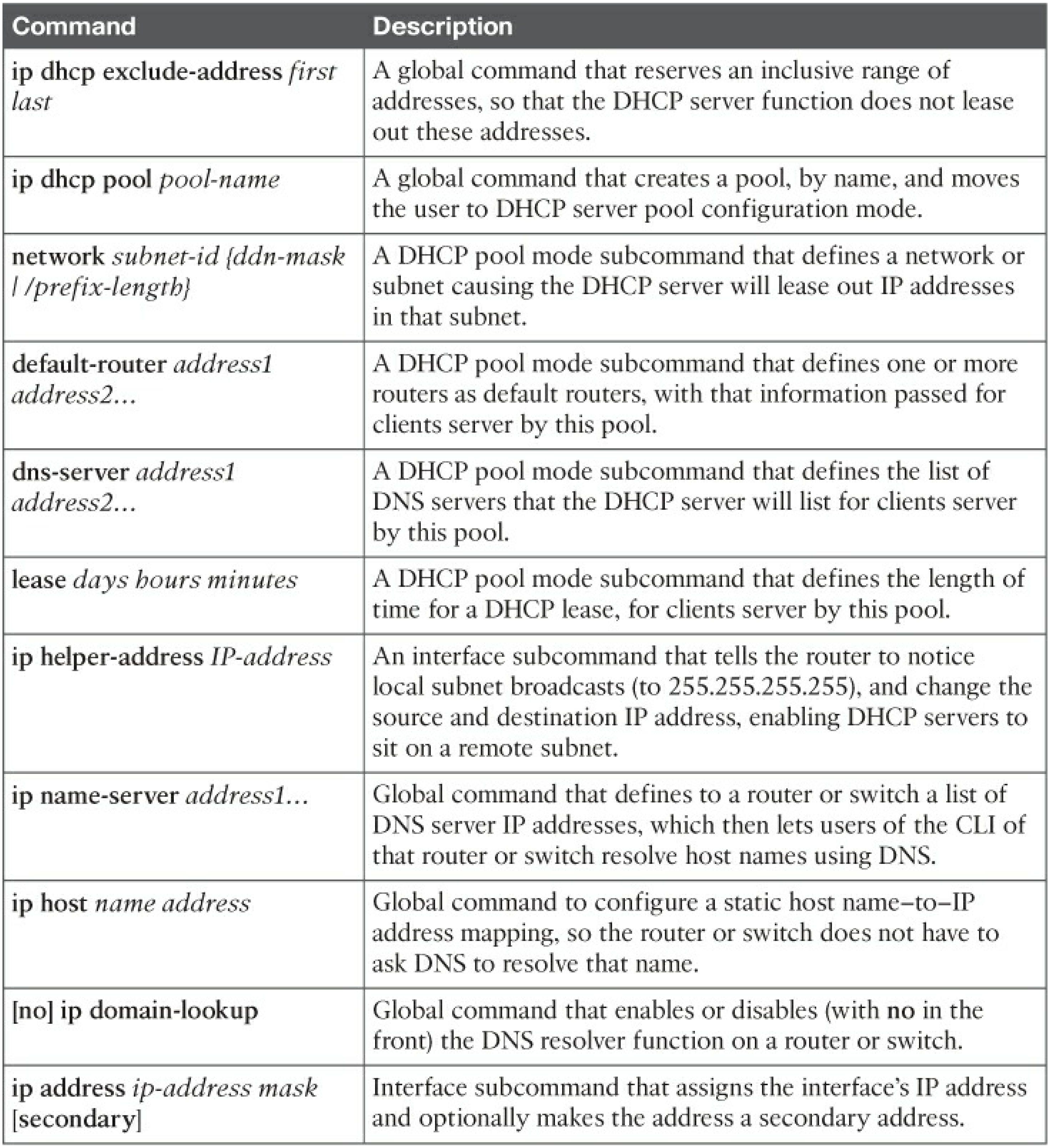
After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

- DHCP client
- DHCP server
- local subnet broadcast address
- ping
- traceroute
- DHCP relay
- ICMP

Command Reference to Check Your Memory

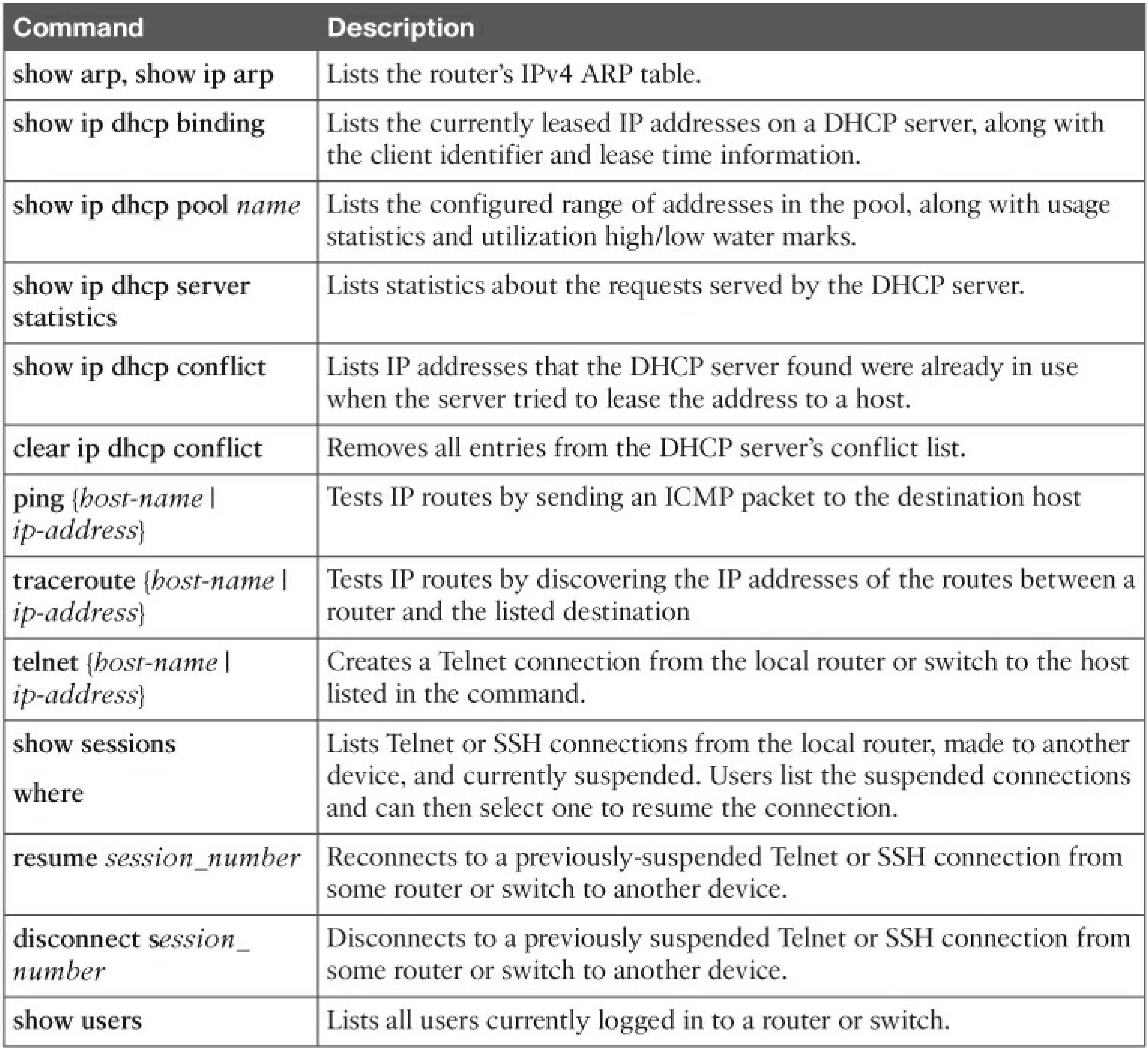
Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. This section also includes a table of the host networking commands mentioned in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To check to see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table with a piece of paper, read the descriptions on the right side, and see whether you remember the command.

Table 18-3. Chapter 18 Configuration Command Reference



Command	Description
ip dhcp exclude-address *first last*	A global command that reserves an inclusive range of addresses, so that the DHCP server function does not lease out these addresses.
ip dhcp pool *pool-name*	A global command that creates a pool, by name, and moves the user to DHCP server pool configuration mode.
network *subnet-id {ddn-mask | /prefix-length}*	A DHCP pool mode subcommand that defines a network or subnet causing the DHCP server will lease out IP addresses in that subnet.
default-router *address1 address2…*	A DHCP pool mode subcommand that defines one or more routers as default routers, with that information passed for clients server by this pool.
dns-server *address1 address2…*	A DHCP pool mode subcommand that defines the list of DNS servers that the DHCP server will list for clients server by this pool.
lease *days hours minutes*	A DHCP pool mode subcommand that defines the length of time for a DHCP lease, for clients server by this pool.
ip helper-address *IP-address*	An interface subcommand that tells the router to notice local subnet broadcasts (to 255.255.255.255), and change the source and destination IP address, enabling DHCP servers to sit on a remote subnet.
ip name-server *address1…*	Global command that defines to a router or switch a list of DNS server IP addresses, which then lets users of the CLI of that router or switch resolve host names using DNS.
ip host *name address*	Global command to configure a static host name–to–IP address mapping, so the router or switch does not have to ask DNS to resolve that name.
[no] ip domain-lookup	Global command that enables or disables (with **no** in the front) the DNS resolver function on a router or switch.
ip address *ip-address mask* [**secondary**]	Interface subcommand that assigns the interface's IP address and optionally makes the address a secondary address.

Table 18-4. Chapter 18 EXEC Command Reference



Command	Description
show arp, show ip arp	Lists the router's IPv4 ARP table.
show ip dhcp binding	Lists the currently leased IP addresses on a DHCP server, along with the client identifier and lease time information.
show ip dhcp pool *name*	Lists the configured range of addresses in the pool, along with usage statistics and utilization high/low water marks.
show ip dhcp server statistics	Lists statistics about the requests served by the DHCP server.
show ip dhcp conflict	Lists IP addresses that the DHCP server found were already in use when the server tried to lease the address to a host.
clear ip dhcp conflict	Removes all entries from the DHCP server's conflict list.
ping {*host-name* | *ip-address*}	Tests IP routes by sending an ICMP packet to the destination host
traceroute {*host-name* | *ip-address*}	Tests IP routes by discovering the IP addresses of the routes between a router and the listed destination
telnet {*host-name* | *ip-address*}	Creates a Telnet connection from the local router or switch to the host listed in the command.
show sessions **where**	Lists Telnet or SSH connections from the local router, made to another device, and currently suspended. Users list the suspended connections and can then select one to resume the connection.
resume *session_number*	Reconnects to a previously-suspended Telnet or SSH connection from some router or switch to another device.
disconnect s*ession_number*	Disconnects to a previously suspended Telnet or SSH connection from some router or switch to another device.
show users	Lists all users currently logged in to a router or switch.

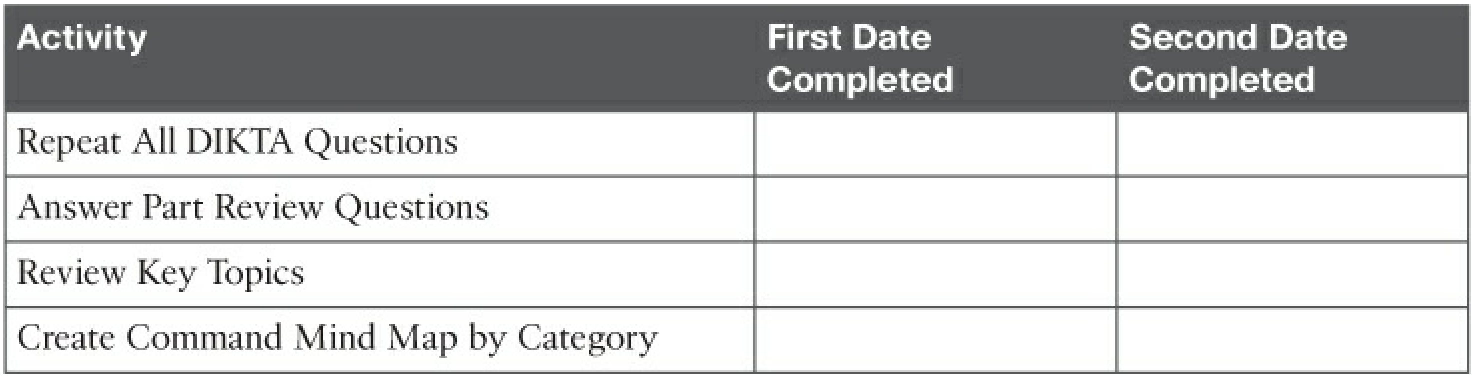
Table 18-5. Chapter 18 Generic Host Networking Command Reference

Command	Description
ipconfig, **ifconfig**	Lists IP settings for the interface (NIC).
nslookup *name*	Performs a name resolution request for the name, and lists the results.
netstat -rn	Lists the hosts routing table, often listing the default router with a route to 0.0.0.0.
arp -a	Lists the host's ARP table.
ping {*host-name* | *ip-address*}	Tests IP routes by sending an ICMP packet to the destination host.
traceroute | **tracert** | **pathping** {*host-name* | *ip-address*}	Tests IP routes by discovering the IP addresses of the routes between a router and the listed destination.

Part IV Review

Keep track of your part review progress with the checklist in Table P4-1. Details on each task follow the table.

Table P4-1. Part IV Part Review Checklist



Activity	First Date Completed	Second Date Completed
Repeat All DIKTA Questions		
Answer Part Review Questions		
Review Key Topics		
Create Command Mind Map by Category		

Repeat All DIKTA Questions

For this task, answer the "Do I Know This Already?" questions again for the chapters in this part of the book, using the PCPT software. Refer to the Introduction to this book, heading "How to View Only DIKTA Questions by Part," for help with how to make the PCPT software show you DIKTA questions for this part only.

Answer Part Review Questions

For this task, answer the Part Review questions for this part of the book, using the PCPT software. Refer to the Introduction to this book, heading "How to View Only Part Review Questions by Part," for help with how to make the PCPT software show you Part Review questions for this part only.

Review Key Topics

Key Topic

Browse back through the chapters, and look for the Key Topics icons. If you do not remember some details, take the time to reread those topics.

Create Command Mind Map by Category

Like Part II of this book, Part IV introduced more than a few CLI commands, this time on routers. The sheer number of commands can be a bit overwhelming, so it helps to take a step back from the details and let your brain sift through what you remember, and what it thinks go together, so that you can then realize which commands you need to review so that you remember them better.

The goal with this mind map exercise is to help you remember the commands. This exercise does not focus on the details, every single parameter of every command, or even their meaning. The goal is to help you organize the commands internally so that you know which commands to consider when faced with a real-life problem or an exam question.

Similar to Part II's mind map, create a mind map with the following categories of commands from this part of the book:

> Interface commands that affect Layers 1 and 2, IP addressing, static and default routing, router trunking and Layer 3 switching, OSPF, DHCP server, connectivity testing, host networking commands, and miscellaneous

Additionally, for more review, you can also include three categories for commands that apply to both routers and switches. These includes the commands that Chapter 15, "Operating Cisco Routers," only briefly reviewed, but were explained back in Part II of this book: Console and VTY, SSH, and router (switch) administration.

In this mind map, for each category, think of all configuration commands and all EXEC commands (mostly show commands). For each category, group the configuration commands separately from the EXEC commands. Figure P4-1 shows a sample for the CDP branch of the commands.

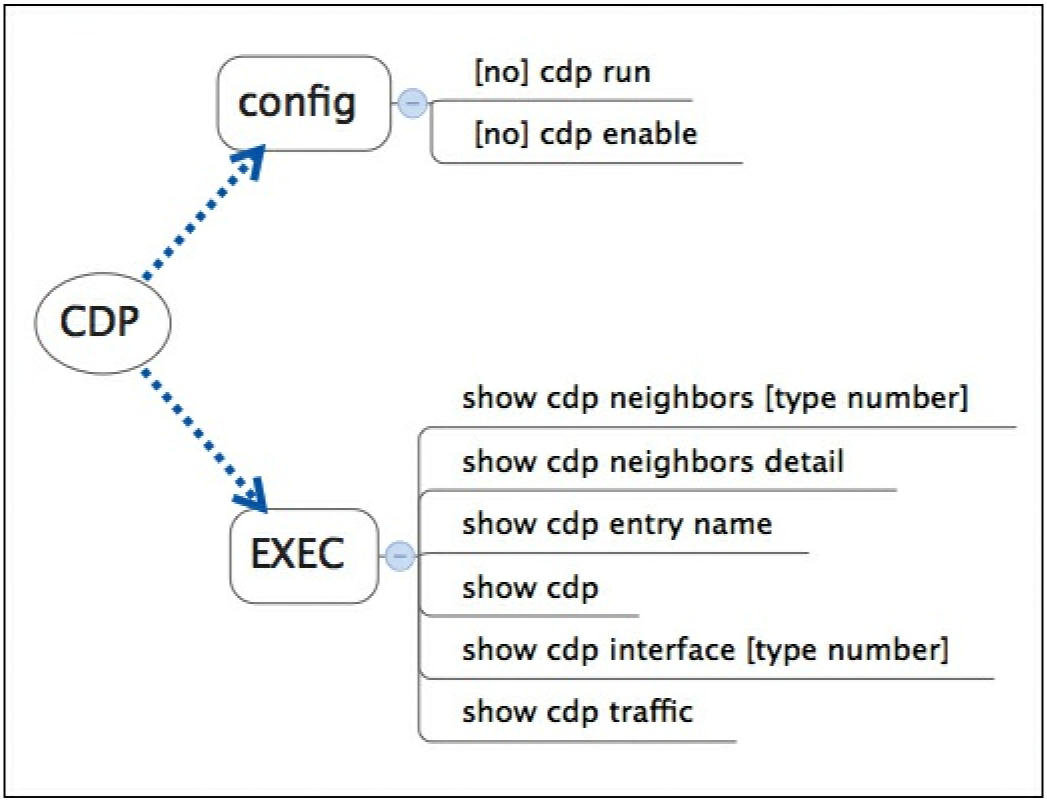

config
[no] cdp run
[no] cdp enable
CDP
EXEC
show cdp neighbors [type number]
show cdp neighbors detail
show cdp entry name
show cdp
show cdp interface [type number]
show cdp traffic

Figure P4-1. Sample Mind Map from the CDP Branch

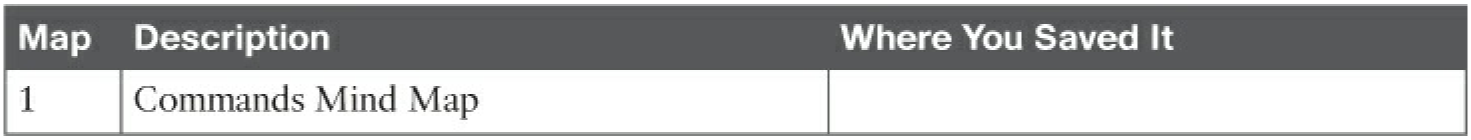
> **Note**
>
> For more information on mind mapping, refer to the Introduction, in the section "About Mind Maps."

Finally, keep the following important points in mind when working on this project:

- Most of the learning with this exercise happens when you do it. Reading some other mind map, or just rereading command tables, does not work as well for helping you remember for yourself.
- Do this activity without notes and without looking at the book.
- After you finish, review it versus the command summary tables at the ends of the chapters and note which commands you had originally forgotten.
- Do not worry about every last parameter, or the exact syntax; just write down the first few words of the command.
- For later study, make a note about which commands you feel you truly understand and which ones about which you feel less confident.
- Repeat this exercise when you have ten spare minutes, as a way to see what you remember (again without your notes).

DVD Appendix O, "Mind Map Solutions," lists a sample mind map answer, but as usual, your mind map can and will look different.

Table P4-2. Configuration Mind Maps for Part IV Review



Map	Description	Where You Saved It
1	Commands Mind Map	

Part V: Advanced IPv4 Addressing Concepts

The first four parts of this book provide enough information so that anyone can implement a small IPv4 network. The next two parts take the discussion a little deeper into IPv4 topics. In particular, Part V focuses on several IPv4 topics that have a lot to do with concepts, but with only a little configuration related to each feature.

All three chapters in this part discuss design choices an engineer can make about an IPv4 network, and describe the meaning of those design choices on how you operate the network. In particular, Chapter 19 discusses subnet design when using a single mask, while Chapter 20 discusses the implications of using multiple subnet masks in one classful network (VLSM). Chapter 21 ends this part by showing you how to reduce the size of IP routing tables using route summarization.

Chapter 19: Subnet Design
Chapter 20: Variable-Length Subnet Masks
Chapter 21: Route Summarization
Part V Review

Chapter 19. Subnet Design

This chapter covers the following exam topics:

IP addressing (IPv4 / IPv6)

Identify the appropriate IPv4 addressing scheme using VLSM and summarization to satisfy addressing requirements in a LAN/WAN environment.

Troubleshooting

Troubleshoot and correct common problems associated with IP addressing and host configurations.

So far in this book, most of the discussion about IPv4 used examples with the addresses and masks already given. This book has shown many examples already, but the examples so far do not ask you to pick the IP address or pick the mask. Instead, as discussed back in Chapter 11, "Perspectives on IPv4 Subnetting," this book so far has assumed that someone else designed the IP addressing and subnetting plan, and this book shows how to implement it.

This chapter turns that model around. It goes back to the progression of building and implementing IPv4, as discussed in Chapter 11, as shown in Figure 19-1. This chapter picks up the story right after some network engineer has chosen a Class A, B, or C network to use for the enterprise's IPv4 network. And then this chapter discusses the design choices related to picking one subnet mask to use for all subnets (the first major section) and what subnet IDs that choice creates (the second major section).

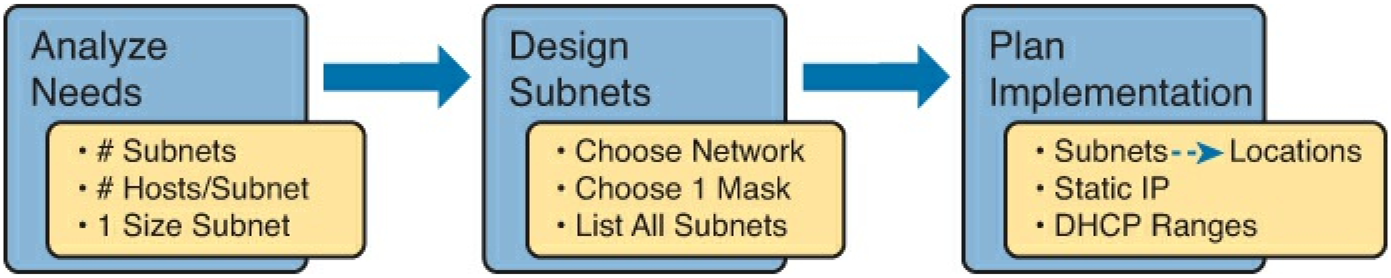


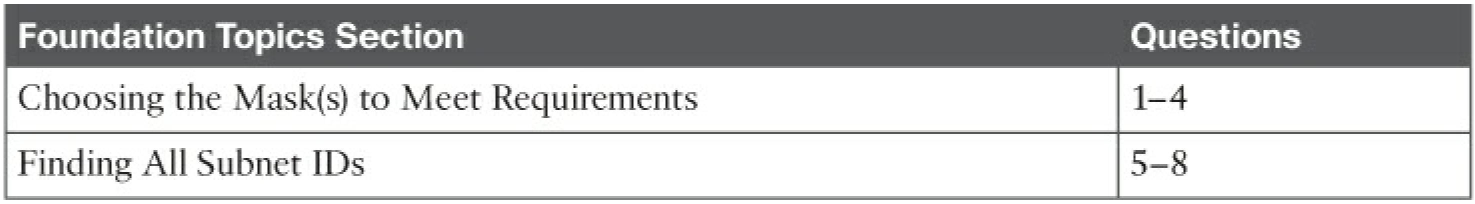
Figure 19-1. Subnet Design and Implementation Process from Chapter 11

Note that Chapter 20, "Variable-Length Subnet Masks," then changes the design choice of using a single mask, instead allowing any mask for each subnet, through the use of variable-length subnet masks (VLSM).

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 19-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Choosing the Mask(s) to Meet Requirements	1–4
Finding All Subnet IDs	5–8

1. An IP subnetting design effort is under way at a company. So far, the senior engineer has decided to use Class B network 172.23.0.0. The design calls for 100 subnets, with the largest subnet needing 500 hosts. Management requires that the design accommodate 50 percent growth in the number of subnets and the size of the largest subnet. The requirements also state that a single mask must be used throughout the Class B network. How many masks meet the requirements?
   - **a.** 0
   - **b.** 1
   - **c.** 2
   - **d.** 3+
2. An IP subnetting design requires 200 subnets and 120 hosts/subnet for the largest subnets, and requires that a single mask be used throughout the one private IP network that will be used. The design also requires planning for 20 percent growth in the number of subnets and number of hosts/subnet in the largest subnet. Which of the following answers lists a private IP network and mask that, if chosen, would meet the requirements?
   - **a.** 10.0.0.0/25
   - **b.** 10.0.0.0/22
   - **c.** 172.16.0.0/23
   - **d.** 192.168.7.0/24

3. An engineer has planned to use Class B network 172.19.0.0 and a single subnet mask throughout the network. The answers list the masks considered by the engineer. Choose the mask that, among the answers, supplies the largest number of hosts per subnet, while also supplying enough subnet bits to support 1000 subnets.
   - **a.** 255.255.255.0
   - **b.** /26
   - **c.** 255.255.252.0
   - **d.** /28
4. A subnet design uses Class A network 10.0.0.0, and the engineer must choose a single mask to use throughout the network. The design requires 1000 subnets, with the largest subnet needing 200 hosts. Which of the following masks meets the requirements and also maximizes the number of subnets?
   - **a.** /18
   - **b.** /20
   - **c.** /22
   - **d.** /24
5. An engineer has calculated the list of subnet IDs, in consecutive order, for network 172.30.0.0/22, assuming that the /22 mask is used throughout the network. Which of the following are true? (Choose two answers.)
   - **a.** Any two consecutive subnet IDs differ by a value of 22 in the third octet.
   - **b.** Any two consecutive subnet IDs differ by a value of 16 in the fourth octet.
   - **c.** The list contains 64 subnet IDs.
   - **d.** The last subnet ID is 172.30.252.0.
6. Which of the following are valid subnet IDs for network 192.168.9.0, using mask /29, assuming that mask /29 is used throughout the network?
   - **a.** 192.168.9.144
   - **b.** 192.168.9.58
   - **c.** 192.168.9.242
   - **d.** 192.168.9.9
7. Which of the following is not a valid subnet ID for network 172.19.0.0, using mask /24, assuming that mask /24 is used throughout the network?
   - **a.** 172.19.0.0
   - **b.** 172.19.1.0
   - **c.** 172.19.255.0
   - **d.** 172.19.0.16
8. Which of the following is not a valid subnet ID for network 10.0.0.0, using mask /25, assuming that this mask is used throughout the network?
   - **a.** 10.0.0.0
   - **b.** 10.255.255.0
   - **c.** 10.255.127.128
   - **d.** 10.1.1.192

Answers to the "Do I Know This Already?" quiz:

1 A **2** B **3** B **4** D **5** C and D **6** A **7** D **8** D

Foundation Topics

Choosing the Mask(s) to Meet Requirements

This first major section examines how to find all the masks that meet the stated requirements for the number of subnets and the number of hosts per subnet. To that end, the text assumes that the designer has already determined these requirements and has chosen the network number to be subnetted. The designer has also made the choice to use a single subnet mask value throughout the classful network.

Armed with the information in this chapter, you can answer questions such as the following, a question that matters both for real engineering jobs and the Cisco exams:

> You are using Class B network 172.16.0.0. You need 200 subnets and 200 hosts/subnet. Which of the following subnet mask(s) meet the requirements? (This question is then followed by several answers that list different subnet masks.)

To begin, this section reviews the concepts in Chapter 11's section "Choose the Mask." That section introduced the main concepts about how an engineer, when designing subnet conventions, must choose the mask based on the requirements.

After reviewing the related concepts from Chapter 11, this section examines this topic in more depth. In particular, this chapter looks at three general cases:

- No masks meet the requirements.
- One and only one mask meets the requirements.
- Multiple masks meet the requirements.

For this last case, the text discusses how to determine all masks that meet the requirements and the trade-offs related to choosing which one mask to use.

Review: Choosing the Minimum Number of Subnet and Host Bits

The network designer must examine the requirements for the number of subnets and number of hosts/subnet, and then choose a mask. As discussed in detail in Chapter 13, "Analyzing Subnet Masks," a classful view of IP addresses defines the three-part structure of an IP address: network, subnet, and host. The network designer must choose the mask so that the number of subnet and host bits (S and H, respectively, in Figure 19-2) meet the requirements.

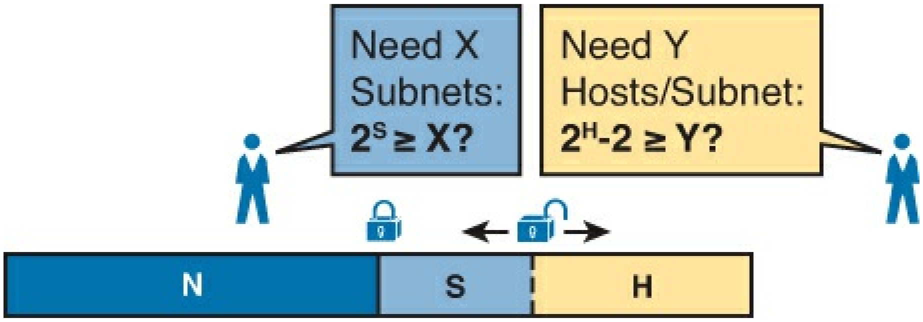


Figure 19-2. Choosing the Number of Subnet and Host Bits

Basically, the designer must choose S subnet bits so that the number of subnets that can be uniquely numbered with S bits (2^S) is at least as large as the required number of subnets. The designer applies similar logic to the number of host bits H, while noting that the formula is $2^H - 2$, because of the two reserved numbers in each subnet. So, keeping the powers of 2 handy, as shown in Table 19-2, will be useful when working through these problems.

Table 19-2. Powers of 2 Reference for Designing Masks

Number of Bits	2^X	Number of Bits	2^X	Number of Bits	2^X	Number of Bits	2^X
1	2	5	32	9	512	13	8192
2	4	6	64	10	1024	14	16,384
3	8	7	128	11	2048	15	32,768
4	16	8	256	12	4096	16	65,536

More formally, the process must determine the minimum values for both S and H that meet the requirements. The following list summarizes the initial steps to choose the mask:

Step 1. Determine the number of network bits (N) based on the class.

Step 2. Determine the smallest value of S, so that 2^S => X, where X represents the required number of subnets.

Step 3. Determine the smallest value of H, so that $2^H - 2$ => Y, where Y represents the required number of hosts/subnet.

The next three sections examine how to use these initial steps to choose a subnet mask.

No Masks Meet Requirements

After you determine the required number of subnet and host bits, those bits might not fit into a 32-bit IPv4 subnet mask. Remember, the mask always has a total of 32 bits, with binary 1s in the network and subnet parts and binary 0s in the host part. For the exam, a question might provide a set of requirements that simply cannot be met with 32 total bits.

For example, consider the following sample exam question:

> A network engineer is planning a subnet design. The engineer plans to use Class B network 172.16.0.0. The network has a need for 300 subnets and 280 hosts per subnet. Which of the following masks could the engineer choose?

The three-step process shown in the previous section shows that these requirements mean that a total of 34 bits will be needed, so no mask meets the requirements. First, as a Class B network, 16 network bits exist, with 16 host bits from which to create the subnet part and to leave enough host bits to number the hosts in each subnet. For the number of subnet bits, S=8 does not work, because $2^8 = 256 < 300$. However, S=9 works, because $2^9 = 512 => 300$. Similarly, because $2^8 - 2 = 254$, which is less than 300, 8 host bits are not enough, but 9 host bits ($2^9 - 2 = 510$) are just enough.

These requirements do not leave enough space to number all the hosts and subnet, because the network, subnet, and host parts add up to more than 32:

> N=16, because as a Class B network, 16 network bits exist.
>
> The minimum S=9, because S=8 provides too few subnets ($2^8 = 256 < 300$), but S=9 provides $2^9 = 512$ subnets.
>
> The minimum H=9, because H=8 provides too few hosts ($2^8 - 2 = 254 < 280$), but H=9 provides $2^9 - 2 = 510$ hosts/subnet.

Figure 19-3 shows the resulting format for the IP addresses in this subnet, after the engineer has allocated 9 subnet bits on paper. Only 7 host bits remain, but the engineer needs 9 host bits.

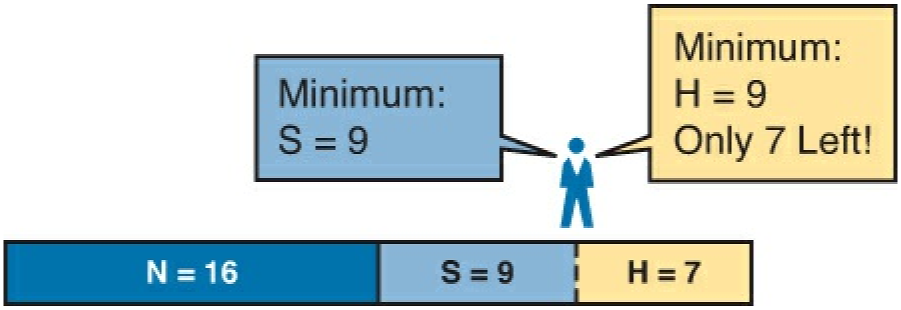


Figure 19-3. Too Few Bits for the Host Part, Given the Requirements

One Mask Meets Requirements

The process discussed in this chapter in part focuses on finding the smallest number of subnet bits and the smallest number of host bits to meet the requirements. If the engineer tries to use these minimum values, and the combined network, subnet, and host parts add up to exactly 32 bits, exactly one mask meets the requirements.

For example, consider a revised version of the example in the previous section, with smaller numbers of subnet and hosts, as follows:

> A network engineer is planning a subnet design. The engineer plans to use Class B network 172.16.0.0. The network has a need for 200 subnets and 180 hosts per subnet. Which of the following masks could the engineer choose?

The three-step process to determine the numbers of network, minimum subnet, and minimum host bits results in a need for 16, 8, and 8 bits, respectively. As before, with a Class B network, 16 network bits exist. With a need for only 200 hosts, S=8 does work, because $2^8 = 256 => 200$; 7 subnet bits would not supply enough subnets ($2^7 = 128$). Similarly, because $2^8 - 2 = 254 => 180$, 8 host bits meet the requirements; 7 host bits (for 126 total hosts/subnet) would not be enough.

Figure 19-4 shows the resulting format for the IP addresses in this subnet.

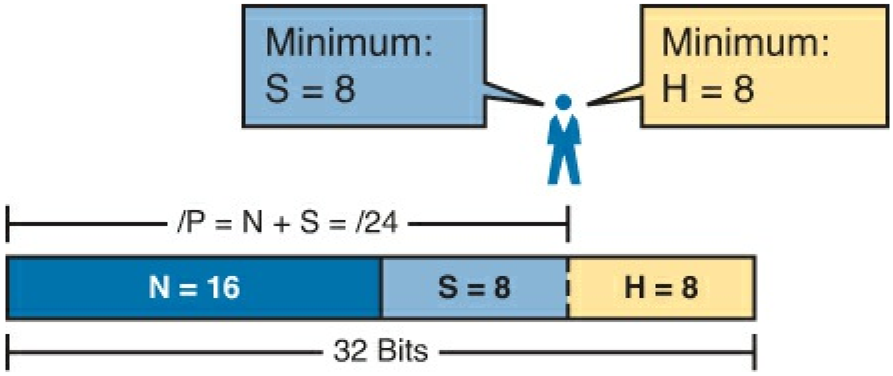


Figure 19-4. One Mask That Meets Requirements

Figure 19-4 shows the mask conceptually. To find the actual mask value, simply record the mask in prefix format (/P), where P = N + S or, in this case, /24.

Multiple Masks Meet Requirements

Depending on the requirements and choice of network, several masks might meet the requirements for the numbers of subnets and hosts/subnet. In these cases, you need to find all the masks that could be used. Then, you have a choice, but what should you consider when choosing one mask among all those that meet your requirements? This section shows how to find all the masks, as well as the facts to consider when choosing one mask from the list.

Finding All the Masks: Concepts

To help you better understand how to find all the subnet masks in binary, this section uses two major steps. In the first major step, you build the 32-bit binary subnet mask on paper. You write down binary 1s for the network bits, binary 1s for the subnet bits, and binary 0s for the host bits, just as always. However, you will use the minimum values for S and H. And when you write down these bits, you will not have 32 bits yet!

For example, consider the following problem, similar to the earlier examples in this chapter, but with some changes in the requirements:

> A network engineer is planning a subnet design. The engineer plans to use Class B network 172.16.0.0. The network has a need for 50 subnets and 180 hosts per subnet. Which of the following masks could the engineer choose?

This example is similar to an earlier example, except that only 50 subnets are needed in this case. Again, the engineer is using private IP network 172.16.0.0, meaning 16 network bits. The design requires only 6 subnet bits in this case, because $2^6 = 64$ => 50, and with only 5 subnet bits, $2^5 = 32 < 50$. The design then requires a minimum of 8 host bits.

One way to discuss the concepts and find all the masks that meet these requirements is to write down the bits in the subnet mask: binary 1s for the network and subnet parts and binary 0s for the host part. However, think of the 32-bit mask as 32-bit positions, and when writing the binary 0s, *write them on the far right*. Figure 19-5 shows the general idea.

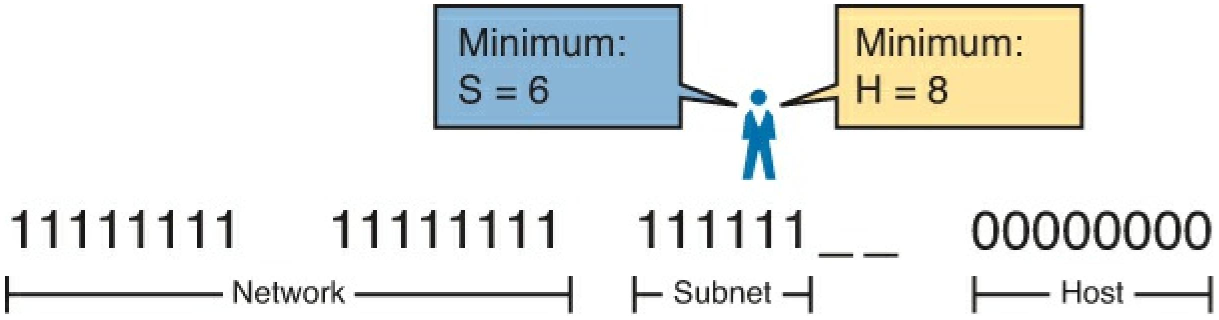


Figure 19-5. Incomplete Mask with N=16, S=6, and H=8

Figure 19-5 shows 30 bits of the mask, but the mask must have 32 bits. The 2 remaining bits might become subnet bits, being set to binary 1. Alternately, these 2 bits could be made host bits, being set to binary 0. The engineer simply needs to choose based on whether he would like more subnet bits, to number more subnets, or more host bits, to number more hosts/subnet.

However, the engineer cannot just choose any value for these 2 bits. The mask must still follow this rule:

Key Topic

> A subnet mask begins with all binary 1s, followed by all binary 0s, with no interleaving of 1s and 0s.

With the example shown in Figure 19-5, with 2 open bits, one value (binary 01) breaks this rule. However, the other three combinations of 2 bits (00, 10, and 11) do not break the rule. As a result, three masks meet the requirements in this example, as shown in Figure 19-6.

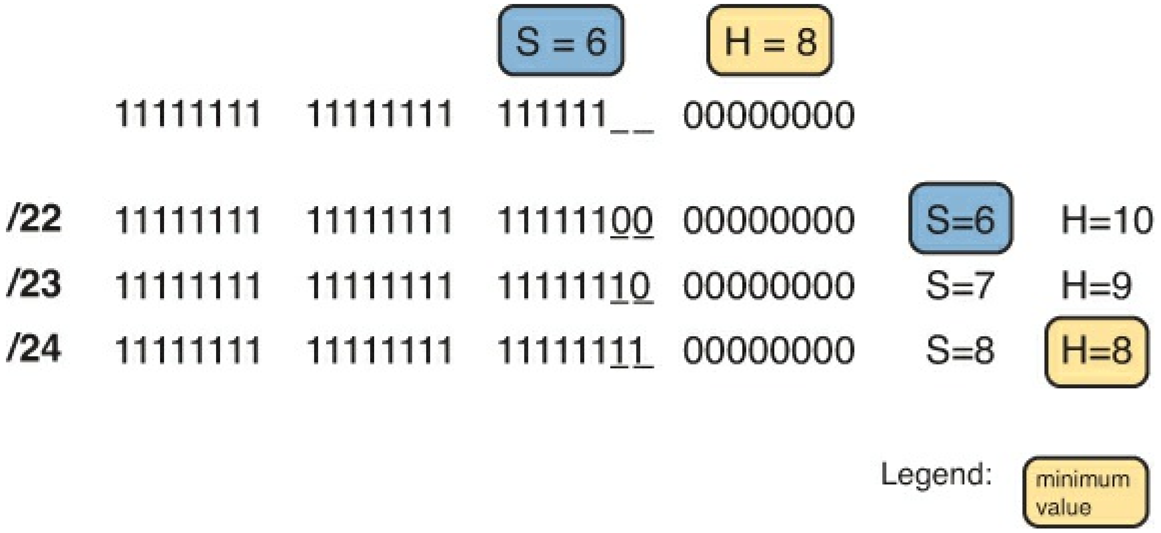

S = 6
H = 8
11111111 11111111 111111_ _ 00000000
/22 11111111 11111111 11111100 00000000 S=6 H=10
/23 11111111 11111111 11111110 00000000 S=7 H=9
/24 11111111 11111111 11111111 00000000 S=8 H=8
Legend: minimum value

Figure 19-6. Three Masks That Meet the Requirements

In the three masks, the first has the least number of subnet bits among the three masks, but therefore has the most number of host bits. So, the first mask maximizes the number of hosts/subnet. The last mask uses the minimum value for the number of host bits, therefore using the most number of subnet bits allowed while still meeting the requirements. As a result, the last mask maximizes the number of subnets allowed.

Finding All the Masks: Math

Although the concepts related to the example shown in Figures 19-5 and 19-6 are important, you can find the range of masks that meets the requirements more easily just using some simple math. The process to find the masks just requires a few steps, after you know N and the minimum values of S and H. The process finds the value of /P when using the least number of subnet bits, and when using the least number of host bits, as follows:

Key Topic

Step 1. Calculate the shortest prefix mask (/P) based on the *minimum value of S*, where P = N + S.

Step 2. Calculate the longest prefix mask (/P) based on the *minimum value of H*, where P = 32 – H.

Step 3. The range of valid masks includes all /P values between the two values calculated in the previous steps.

For example, in the example shown in Figure 19-6, N = 16, the minimum S = 6, and the minimum H = 8. The first step identifies the shortest prefix mask (the /P with the smallest value of P) of *22 by adding N and S (16 + 6). The second step identifies the longest prefix mask that meets the requirements by subtracting the smallest possible value for H (8, in this case) from 32, for a mask of* 24. The third step reminds us that the range is from *22 to* 24, meaning that /23 is also an option.

Choosing the Best Mask

When multiple possible masks meet the stated requirements, the engineer has a choice of masks. That, of course, begs some questions: Which mask should you choose? Why would one mask be better than the other? The reasons can be summarized into three main options:

Key Topic

To maximize the number of hosts/subnet: To make this choice, use the shortest prefix mask (that is, the mask with the smallest /P value), because this mask has the largest host part.

To maximize the number of subnets: To make this choice, use the longest prefix mask (that is, the mask with the largest /P value), because this mask has the largest subnet part.

To increase both the numbers of supported subnets and hosts: To make this choice, choose a mask in the middle of the range, which gives you both more subnet bits and more host bits.

For example, in Figure 19-6, the range of masks that meet the requirements is /22 – /24. The shortest mask, *22, has the least subnet bits but the largest number of host bits (10) of the three answers, maximizing the number of hosts*subnet. The longest mask, *24, maximizes the number of subnet bits (8), maximizing the number of subnets, at least among the options that meet the original requirements. The mask in the middle,* 23, provides some growth in both subnets and hosts/subnet.

The Formal Process

Although this chapter has explained various steps in finding a subnet mask to meet the design requirements, it has not yet collected these concepts into a list for the entire process. The following list collects all these steps into one place for reference. Note that this list does not introduce any new concepts compared to the rest of this chapter—it just puts all the ideas in one place:

Key Topic

Step 1. Find the number of network bits (N) per class rules.

Step 2. Calculate the minimum number of subnet bits (S) so that 2^S => the number of required subnets.

Step 3. Calculate the minimum number of host bits (H) so that 2^H – 2 => the number of required hosts/subnet.

Step 4. If N + S + H > 32, no mask meets the need.

Step 5. If N + S + H = 32, one mask meets the need. Calculate the mask as /P, where P = N + S.

Step 6. If N + S + H < 32, multiple masks meet the need:

  A. Calculate mask /P based on the minimum value of S, where P = N + S. This mask maximizes the number of hosts/subnet.

  B. Calculate mask /P based on the minimum value of H, where P = 32 – H. This mask maximizes the number of possible subnets.

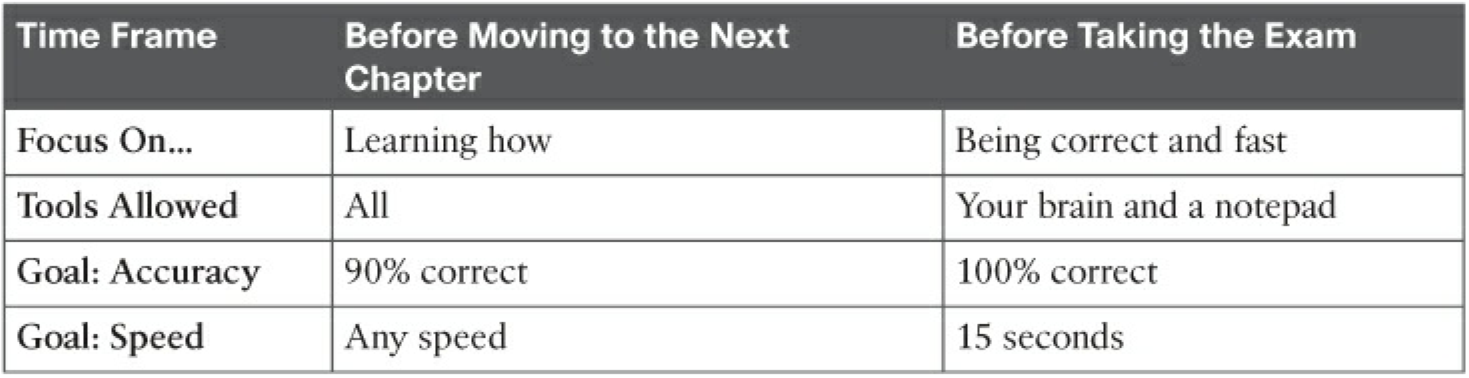
C. Note that the complete range of masks includes all prefix lengths between the two values calculated in Steps 6A and 6B.

Practice Choosing Subnet Masks

Before moving on to the next section, practice until you get the right answer most of the time—but use any tools you want and take all the time you need. Then, you can move on with your reading.

However, before taking the exam, practice until you master the topics in this chapter and can move pretty fast. As for time, you should try to find the entire answer—all the masks that meet the requirements, which maximizes the number of subnets, and which maximizes the number of hosts—in around 15 seconds. Table 19-3 summarizes the key concepts and suggestions for this two-phase approach.

Table 19-3. Keep-Reading and Take-Exam Goals for Choosing a Subnet Mask



Time Frame	Before Moving to the Next Chapter	Before Taking the Exam
Focus On...	Learning how	Being correct and fast
Tools Allowed	All	Your brain and a notepad
Goal: Accuracy	90% correct	100% correct
Goal: Speed	Any speed	15 seconds

Practice Problems for Choosing a Subnet Mask

The following list shows three separate problems, each with a classful network number and a required number of subnets and hosts/subnet. For each problem, determine the minimum number of subnet and host bits that meet the requirements. If more than one mask exists, note which mask maximizes the number of hosts/subnet and which maximizes the number of subnets. If only one mask meets the requirements, simply list that mask. List the masks in prefix format:

1. Network 10.0.0.0, need 1500 subnets, need 300 hosts/subnet
2. Network 172.25.0.0, need 130 subnets, need 127 hosts/subnet
3. Network 192.168.83.0, need 8 subnets, need 8 hosts/subnet

Table 19-6, found in the later section "Answers to Earlier Practice Problems," lists the answers.

Additional Practice for Choosing the Subnet Mask

This section lists several options for additional practice:

- Appendix G, "Practice for Chapter 19: Subnet Design," has some additional practice problems listed with explanations.
- Create your own problems. Many subnet calculators let you type the Class A, B, or C network and choose the mask, and the calculator then lists the number of subnets and hosts/subnet created by that network/mask. Make up a network number and required numbers of subnets and hosts, derive the answers, and check the math with the calculator. This can take a little more work with a calculator as compared with some of the other subnetting chapters in this book.

Finding All Subnet IDs

After the person designing the IP subnetting plan has chosen the one mask to use throughout the Class A, B, or C network, he will soon need to start assigning specific subnet IDs for use in specific VLANs, serial links, and other places in the internetwork that need a subnet. But what are those subnet IDs? As it turns out, after the network ID and one subnet mask for all subnets have been chosen, finding all the subnet IDs just requires doing a little math. This second major section of this chapter focuses on that math, which focuses on a single question:

> Given a single Class A, B, or C network, and the single subnet mask to use for all subnets, what are all the subnet IDs?

When learning how to answer this question, you can think about the problem in either binary or decimal. This chapter approaches the problem using decimal. Although the process itself requires only simple math, the process requires practice before most people can confidently answer this question.

The decimal process begins by identifying the first, or numerically lowest, subnet ID. After that, the process identifies a pattern in all subnet IDs for a given subnet mask so that you can find each successive subnet ID through simple addition. This section examines the key ideas behind this process first; then you are given a formal definition of the process.

Note

Some videos included on the accompanying DVD describe the same fundamental processes to find all subnet IDs. You can view those videos before or after reading this section, or even instead of reading this section, as long as you learn how to independently find all subnet IDs. The process step numbering in the videos might not match the steps shown in this edition of the book.

First Subnet ID: The Zero Subnet

The first step in finding all subnet IDs of one network is incredibly simple: Copy the network ID. That is, take the Class A, B, or C network ID—in other words, the classful network ID—and write it down as the first subnet ID. No matter what Class A, B, or C network you use, and no matter what subnet mask you use, the first (numerically lowest) subnet ID is equal to the network ID.

For example, if you begin with classful network 172.20.0.0, no matter what the mask is, the first subnet ID is 172.20.0.0.

This first subnet ID in each network goes by two special names: either *subnet zero* or the *zero subnet*. The origin of these names is related to the fact that a network's zero subnet, when viewed in binary, has a subnet part of all binary 0s. In decimal, the zero subnet can be easily identified, because the zero subnet always has the exact same numeric value as the network ID itself.

Note

In years past, IP subnet designs typically avoided the use of the zero subnet because of the confusion that might arise with a network ID and subnet ID that were the exact same numbers.

Finding the Pattern Using the Magic Number

Subnet IDs follow a predictable pattern, at least when using our assumption of a single subnet mask for all subnets of a network. The pattern uses the *magic number*, as discussed in Chapter 14, "Analyzing Existing Subnets." To review, the magic number is 256, minus the mask's decimal value, in a particular octet that this book refers to as the *interesting octet*.

Figure 19-7 shows four examples of these patterns with four different masks. For example, just look at the top of the figure to start. It lists mask 255.255.128.0 on the left. The third octet is the interesting octet, with a mask value other than 0 or 255 in that octet. The left side shows a magic number calculated as 256 – 128 = 128. So, the pattern of subnet IDs is shown in the highlighted number line; that is, the subnet IDs when using this mask will have either a 0 or 128 in the third octet. For example, if using network 172.16.0.0, the subnet IDs would be 172.16.0.0 and 172.16.128.0.

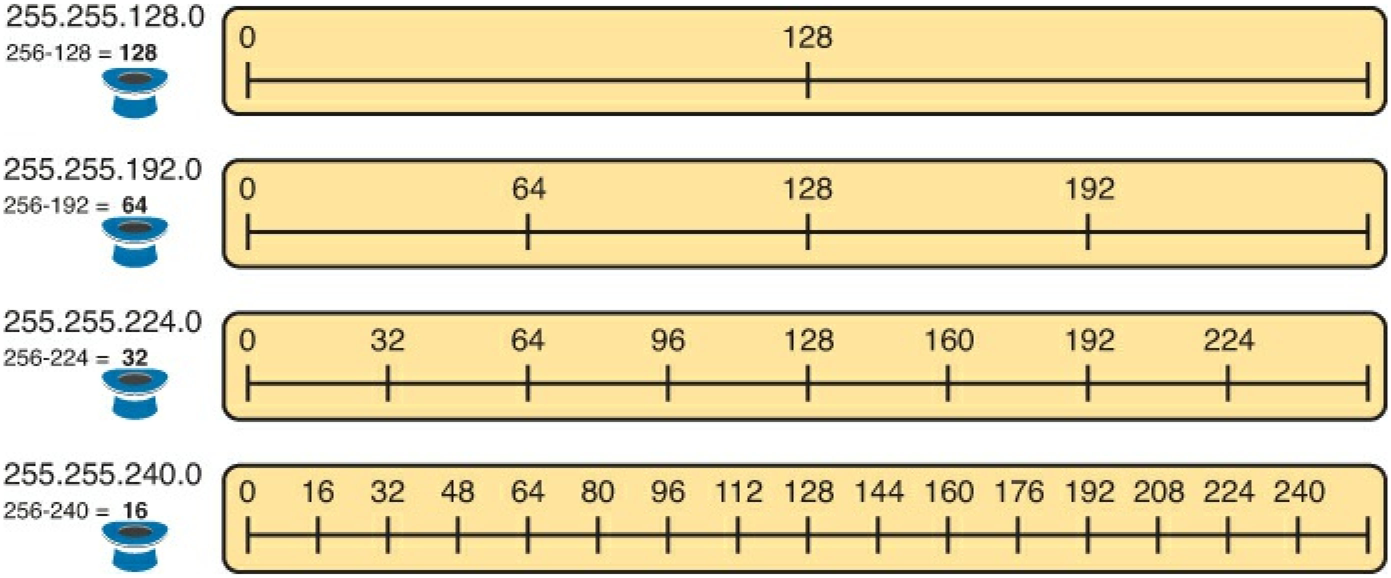


Figure 19-7. Patterns with Magic Numbers for Masks /17 – /20

Now focus on the second row, with another example, with mask 255.255.192.0. This row shows a magic number of 64 (256 – 192 = 64), so the subnet IDs will use a value of 0, 64, 128, or 192 (multiples of 64) in the third octet. For example, if used with network 172.16.0.0, the subnet IDs would be 172.16.0.0, 172.16.64.0, 172.16.128.0, and 172.16.192.0.

Looking at the third row/example, the mask is 255.255.224.0, with a magic number of 256 – 224 = 32. So, as seen in the center of the figure, the subnet ID values will be multiples of 32. For example, if used with network 172.16.0.0 again, this mask would tell us that the subnet IDs are 172.16.0.0, 172.16.32.0, 172.16.64.0, 172.16.96.0, and so on.

Finally, for the bottom example, mask 255.255.240.0 makes the magic number, in the third octet, be 16. So, all the subnet IDs will be a multiple of 16 in the third octet, with those values shown in the middle of the figure.

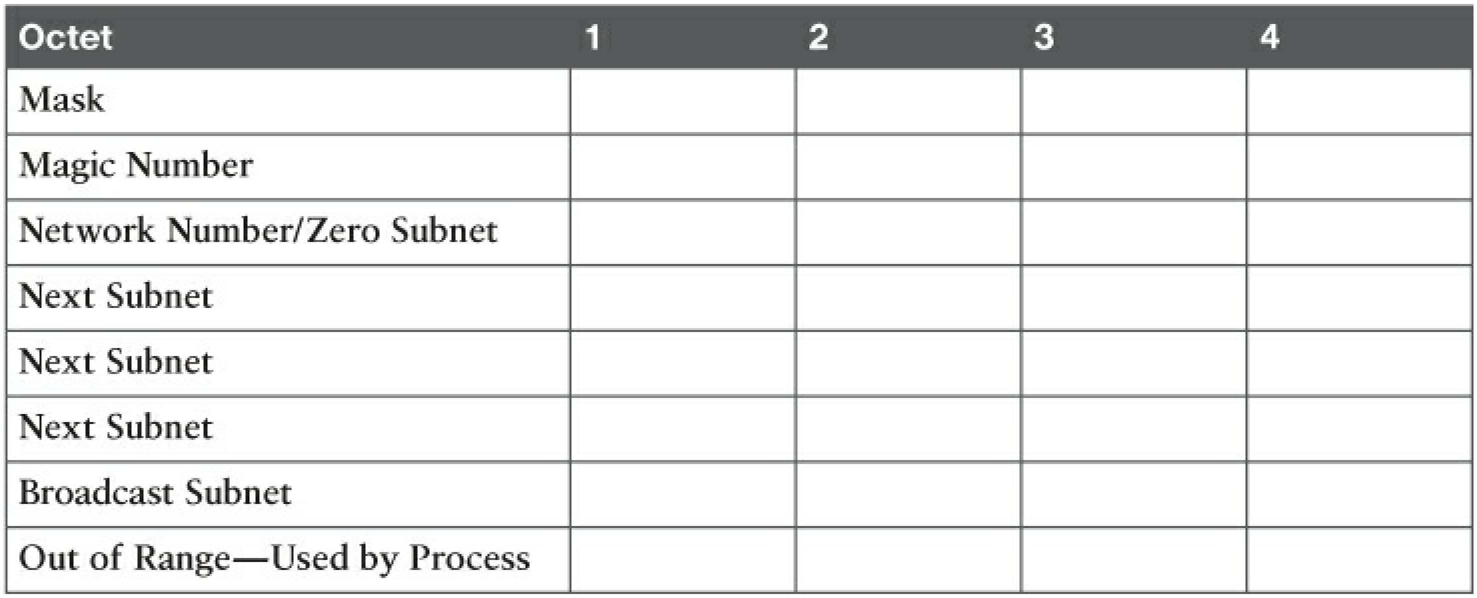
A Formal Process with Less Than 8 Subnet Bits

Although it can be easy to see the patterns in Figure 19-7, it might not be as obvious exactly how to apply those concepts to find all the subnet IDs in every case. This section outlines a specific process to find all the subnet IDs.

To simplify the explanations, this section assumes that less than 8 subnet bits exist. Later, the section "Finding All Subnets with More Than 8 Subnet Bits," describes the full process that can be used in all cases.

First, to organize your thoughts, you might want to organize the data into a table like Table 19-4. This book refers to this chart as the list-all-subnets chart.

Table 19-4. Generic List-All-Subnets Chart



Octet	1	2	3	4
Mask				
Magic Number				
Network Number/Zero Subnet				
Next Subnet				
Next Subnet				
Next Subnet				
Broadcast Subnet				
Out of Range—Used by Process				

A formal process to find all subnet IDs, given a network and a single subnet mask, is as follows:

Step 1. Write down the subnet mask, in decimal, in the first empty row of the table.

Step 2. Identify the interesting octet, which is the one octet of the mask with a value other than 255 or 0. Draw a rectangle around the column of the interesting octet.

Step 3. Calculate and write down the magic number by subtracting the *subnet mask's interesting octet* from 256.

Step 4. Write down the classful network number, which is the same number as the zero subnet, in the next empty row of the list-all-subnets chart.

Step 5. To find each successive subnet number:

- **A.** For the three uninteresting octets, copy the previous subnet number's values.
- **B.** For the interesting octet, add the magic number to the previous subnet number's interesting octet.

Step 6. When the sum calculated in Step 5B reaches 256, stop the process. The number with the 256 in it is out of range, and the previous subnet number is the broadcast subnet.

Although the written process is long, with practice, most people can find the answers much more quickly with this decimal-based process than by using binary math. As usual, most people learn this process best by seeing it in action, exercising it, and then practicing it. To that end, review the two following examples and watch any videos that came with this book that show additional examples.

Example 1: Network 172.16.0.0, Mask 255.255.240.0

To begin this example, focus on the first four of the six steps, when subnetting network 172.16.0.0 using mask 255.255.240.0. Figure 19-8 shows the results of these first four steps:

Step 1. Record mask 255.255.240.0, which was given as part of the problem statement. (Figure 19-8 also shows the network ID, 172.16.0.0, for easy reference.)

Step 2. The mask's third octet is neither 0 nor 255, which makes the third octet interesting.

Step 3. Because the mask's value in the third octet is 240, the magic number = 256 – 240 = 16.

Step 4. Because the network ID is 172.16.0.0, the first subnet ID, the zero subnet, is also 172.16.0.0.

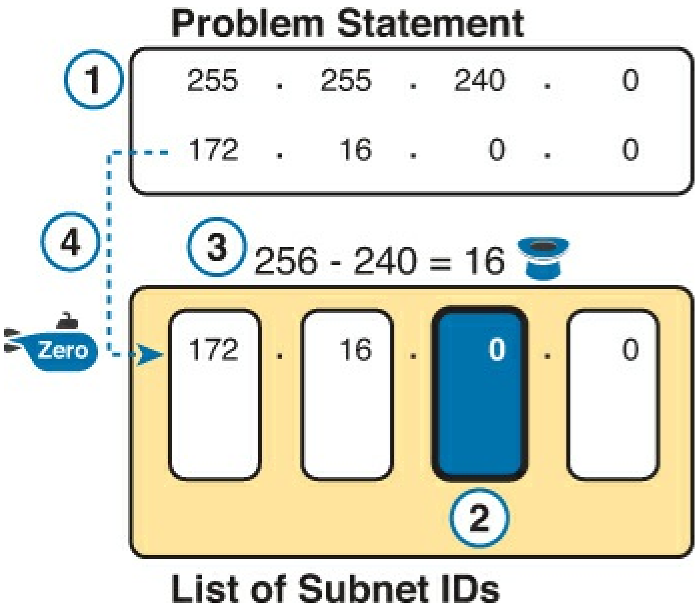

Problem Statement
1
255 . 255 . 240 . 0
172 . 16 . 0 . 0
4
3
256 - 240 = 16
Zero
172 . 16 . 0 . 0
2
List of Subnet IDs

Figure 19-8. Results of First Four Steps: 172.16.0.0, 255.255.240.0.

These first four steps discover the first subnet (the zero subnet) and get you ready to do the remaining steps by identifying the interesting octet and the magic number. Step 5 in the process tells you to copy the three boring octets and add the magic number (16, in this case) in the interesting octet (octet 3, in this case). Keep repeating this step until the interesting octet value equals 256 (per Step 6). When the total is 256, you have listed all the subnet IDs, and the line with 256 on it is not a correct subnet ID. Figure 19-9 shows the results of these steps.

Key Topic

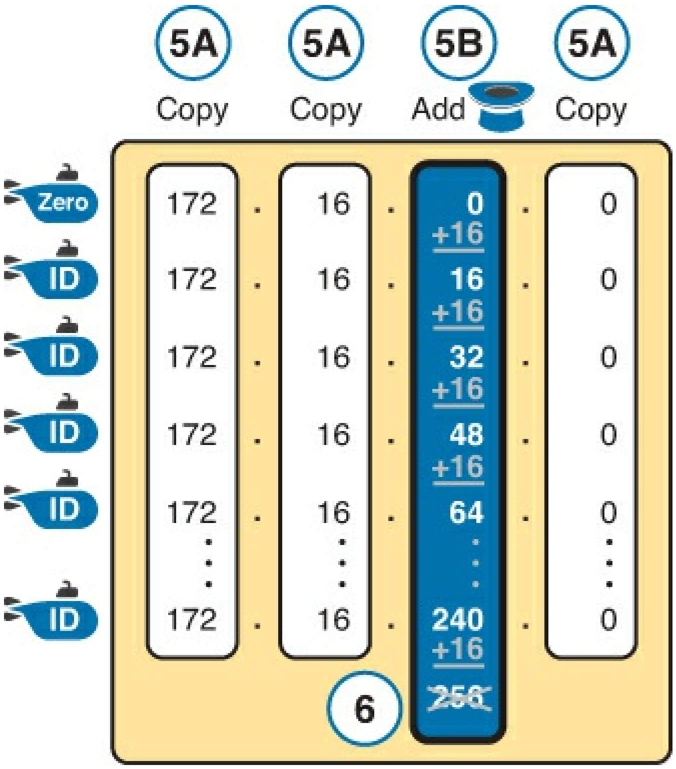

5A
Copy
5A
Copy
5B
Add
5A
Copy
Zero
172 . 16 . 0 . 0
+16
ID
172 . 16 . 16 . 0
+16
ID
172 . 16 . 32 . 0
+16
ID
172 . 16 . 48 . 0
+16
ID
172 . 16 . 64 . 0
ID
172 . 16 . 240 . 0
+16
256
6

Figure 19-9. List of Subnet IDs: 172.16.0.0, 255.255.240.0

Note

In any list of all the subnet IDs of a network, the numerically highest subnet ID is called the *broadcast subnet*. Decades ago, engineers avoided using the broadcast subnet. However, using the broadcast subnet causes no problems. The term *broadcast subnet* has its origins in the fact that if you determine the subnet broadcast address inside the broadcast subnet, it has the same numeric value as the network-wide broadcast address.

Note

People sometimes confuse the terms *broadcast subnet* and *subnet broadcast address*. The *broadcast subnet* is one subnet, namely the numerically highest subnet; only one such subnet exists per network. The term *subnet broadcast address* refers to the one number in each and every subnet that is the numerically highest number in that subnet.

Example 2: Network 192.168.1.0, Mask 255.255.255.224

With a Class C network and a mask of 255.255.255.224, this example makes the fourth octet the interesting octet. However, the process works the same, with the same logic, just with the interesting logic applied in a different octet. As with the previous example, the following list outlines the first four steps, with Figure 19-10 showing the results of the first four steps:

Step 1. Record mask 255.255.255.224, which was given as part of the problem statement, and optionally record the network number (192.168.1.0).

Step 2. The mask's fourth octet is neither 0 nor 255, which makes the fourth octet interesting.

Step 3. Because the mask's value in the fourth octet is 224, the magic number = 256 − 224 = 32.

Step 4. Because the network ID is 192.168.1.0, the first subnet ID, the zero subnet, is also 192.168.1.0.

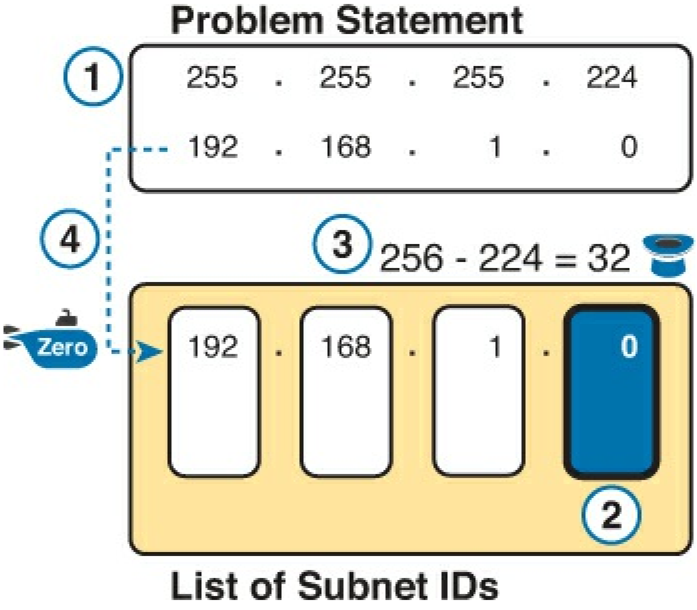

Problem Statement
1
255 . 255 . 255 . 224
192 . 168 . 1 . 0
4
3
256 - 224 = 32
Zero
192 . 168 . 1 . 0
2
List of Subnet IDs

Figure 19-10. Results of First Four Steps: 192.168.1.0, 255.255.255.224

From this point, Step 5 in the process tells you to copy the values in the first three octets and then add the magic number (32, in this case) in the interesting octet (octet 4, in this case). Keep doing so until the interesting octet value equals 256 (per Step 6). When the total is 256, you have listed all the subnet IDs, and the line with 256 on it is not a correct subnet ID. Figure 19-11 shows the results of these steps.

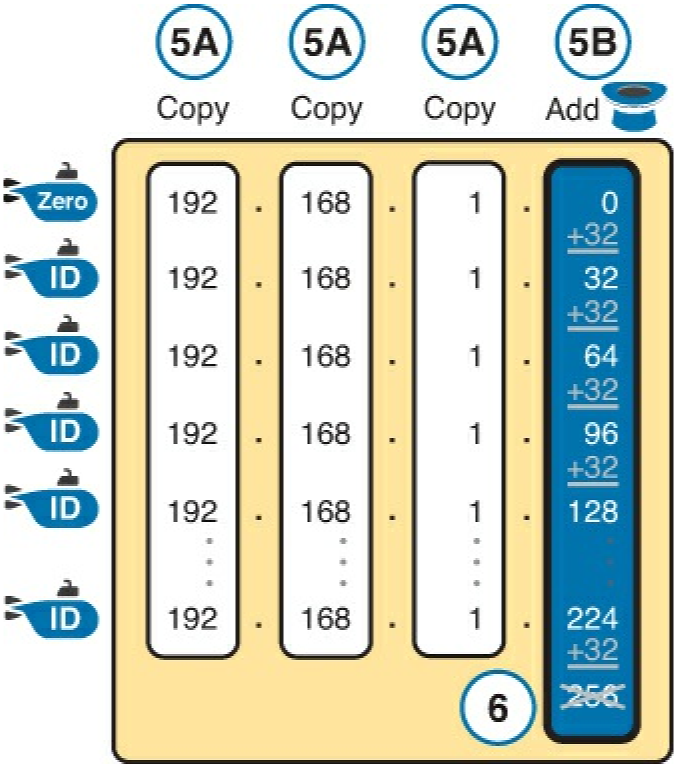

5A
Copy
5A
Copy
5A
Copy
5B
Add
Zero
192 . 168 . 1 . 0
+32
ID
192 . 168 . 1 . 32
+32
ID
192 . 168 . 1 . 64
+32
ID
192 . 168 . 1 . 96
+32
ID
192 . 168 . 1 . 128
ID
192 . 168 . 1 . 224
+32
~~256~~
6

Figure 19-11. List of Subnet IDs: 192.168.1.0, 255.255.255.224

Finding All Subnets with Exactly 8 Subnet Bits

The formal process in the earlier section "A Formal Process with Less Than 8 Subnet Bits" identified the interesting octet as the octet whose mask value is neither a 255 nor a 0. If the mask defines exactly 8 subnet bits, you have to use a different logic to identify the interesting octet; otherwise, the same process can be used. In fact, the actual subnet IDs can be a little more intuitive.

Only two cases exist with exactly 8 subnet bits:

- A Class A network with mask 255.255.0.0; the entire second octet contains subnet bits.
- A Class B network with mask 255.255.255.0; the entire third octet contains subnet bits.

In each case, use the same process as with less than 8 subnet bits, but identify the interesting octet as the one octet that contains subnet bits. Also, because the mask's value is 255, the magic number will be 256 – 255 = 1, so the subnet IDs are each 1 larger than the previous subnet ID.

For example, for 172.16.0.0, mask 255.255.255.0, the third octet is the interesting octet and the magic number is 256 – 255 = 1. You start with the zero subnet, equal in value to network number 172.16.0.0, and then add 1 in the third octet. For example, the first four subnets are as follows:

172.16.0.0 (zero subnet)
172.16.1.0
172.16.2.0
172.16.3.0

Finding All Subnets with More Than 8 Subnet Bits

Earlier, the section "A Formal Process with Less Than 8 Subnet Bits" assumed less than 8 subnet bits for the purpose of simplifying the discussions while you learn. In real life, you need to be able to find all subnet IDs with any valid mask, so you cannot assume less than 8 subnet bits.

The examples that have at least 9 subnet bits have a minimum of 512 subnet IDs, so writing down such a list would take a lot of time. To conserve space, the examples will use shorthand, rather than list hundreds or thousands of subnet IDs.

The process with less than 8 subnet bits told you to count in increments of the magic number in one octet. With more than 8 subnet bits, the new expanded process must tell you how to count in multiple octets. So, this section breaks down two general cases: (a) when 9–16 subnet bits exist, which means that the subnet field exists in only two octets, and (b) cases with 17 or more subnet bits, which means that the subnet field exists in three octets.

Process with 9–16 Subnet Bits

To understand the process, you need to know a few terms that the process will use. Figure 19-12 shows the details, with an example that uses Class B network 130.4.0.0 and mask 255.255.255.192. The lower part of the figure details the structure of the addresses per the mask: a network part of two octets because it is a Class B address, a 10-bit subnet part per the mask (/26), and 6 host bits.

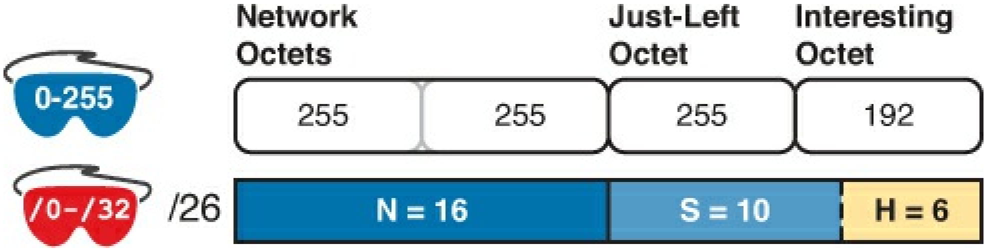


Figure 19-12. Fundamental Concepts and Terms for the >8 Subnet Bit Process

In this case, subnet bits exist in two octets: octets 3 and 4. For the purposes of the process, the rightmost of these octets is the interesting octet, and the octet just to the left is the cleverly named *just-left* octet.

The updated process tells you to count in increments of the magic number in the interesting octet, but count by 1s in the just-left octet. Formally:

Key Topic

Step 1. Calculate subnet IDs using the 8-subnet-bits-or-less process. However, when the total adds up to 256, move to the next step; consider the subnet IDs listed so far as a *subnet block*.

Step 2. Copy the previous subnet block, but add 1 to the just-left octet in all subnet IDs in the new block.

Step 3. Repeat Step 2 until you create the block with a just-left octet of 255, but go no further.

To be honest, the formal concept can cause you problems until you work through some examples, so even if the process remains a bit unclear in your mind, you should work through the following examples instead of rereading the formal process.

First, consider an example based on Figure 19-12, with network 130.4.0.0 and mask 255.255.255.192. Figure 19-12 already showed the structure, and Figure 19-13 shows the subnet ID block created at Step 1.

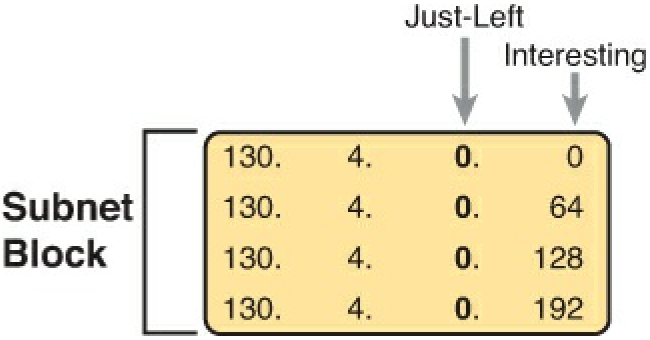

Just-Left
Interesting
Subnet Block
130. 4. 0. 0
130. 4. 0. 64
130. 4. 0. 128
130. 4. 0. 192

Figure 19-13. Step 1: Listing the First Subnet ID Block

The logic at Step 1, to create this subnet ID block of four subnet IDs, follow the same magic number process seen before. The first subnet ID, 130.4.0.0, is the zero subnet. The next three subnet IDs are each 64 bigger, because the magic number, in this case, is 256 − 192 = 64.

Steps 2 and 3 from the formal process tell you how to create 256 subnet blocks, and by doing so, you will list all 1024 subnet IDs. To do so, create 256 total subnet blocks: one with a 0 in the just-left octet, one with a 1 in the just-left octet, and another with a 2 in the just-left octet, up through 255. The process continues through the step at which you create the subnet block with 255 in the just-left octet (third octet, in this case). Figure 19-14 shows the idea, with the addition of the first few subnet blocks.

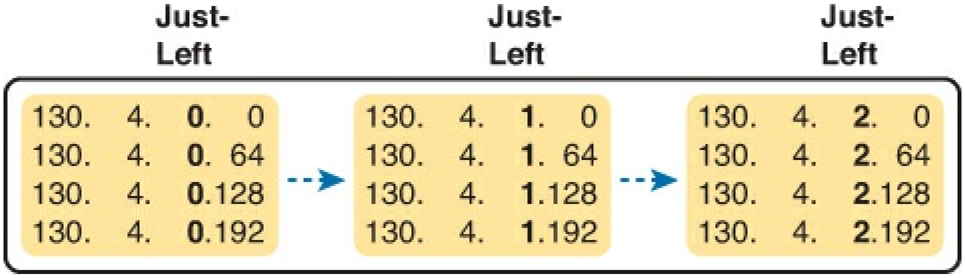

Just-Left
Just-Left
Just-Left
130. 4. 0. 0
130. 4. 0. 64
130. 4. 0.128
130. 4. 0.192
130. 4. 1. 0
130. 4. 1. 64
130. 4. 1.128
130. 4. 1.192
130. 4. 2. 0
130. 4. 2. 64
130. 4. 2.128
130. 4. 2.192

Figure 19-14. Step 2: Replicating the Subnet Block with +1 in the Just-Left Octet

This example, with 10 total subnet bits, creates 256 blocks of four subnets each, for a total of 1024 subnets. This math matches the usual method of counting subnets, because 2^{10} = 1024.

Process with 17 or More Subnet Bits

To create a subnet design that allows 17 or more subnet bits to exist, the design must use a Class A network. Additionally, the subnet part will consist of the entire second and third octets, plus part of the fourth octet. That means a lot of subnet IDs: at least 2^{17} (or 131,072) subnets. Figure 19-15 shows an example of just such a structure, with a Class A network and a /26 mask.

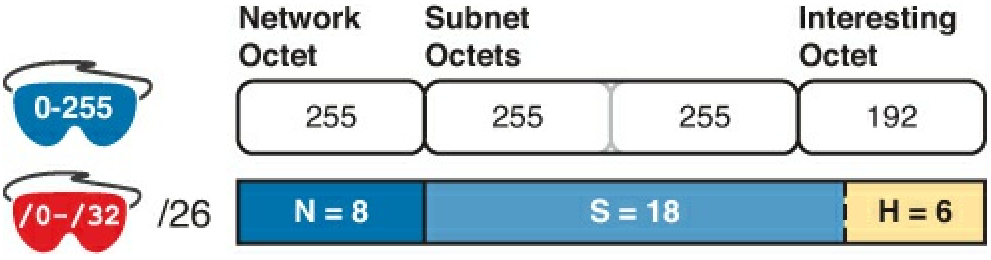

Network Octet
Subnet Octets
Interesting Octet
0-255
255
255
255
192
/0-/32
/26
N = 8
S = 18
H = 6

Figure 19-15. Address Structure with 18 Subnet Bits

To find all the subnet IDs in this example, you use the same general process as with 9–16 subnet bits, but with many more subnet blocks to create. In effect, you have to create a subnet block for all combinations of values (0–255, inclusive) in both the second and third octet. Figure 19-16 shows the general idea. Note that with only 2 subnet bits in the fourth octet in this example, the subnet blocks will have four subnets each.

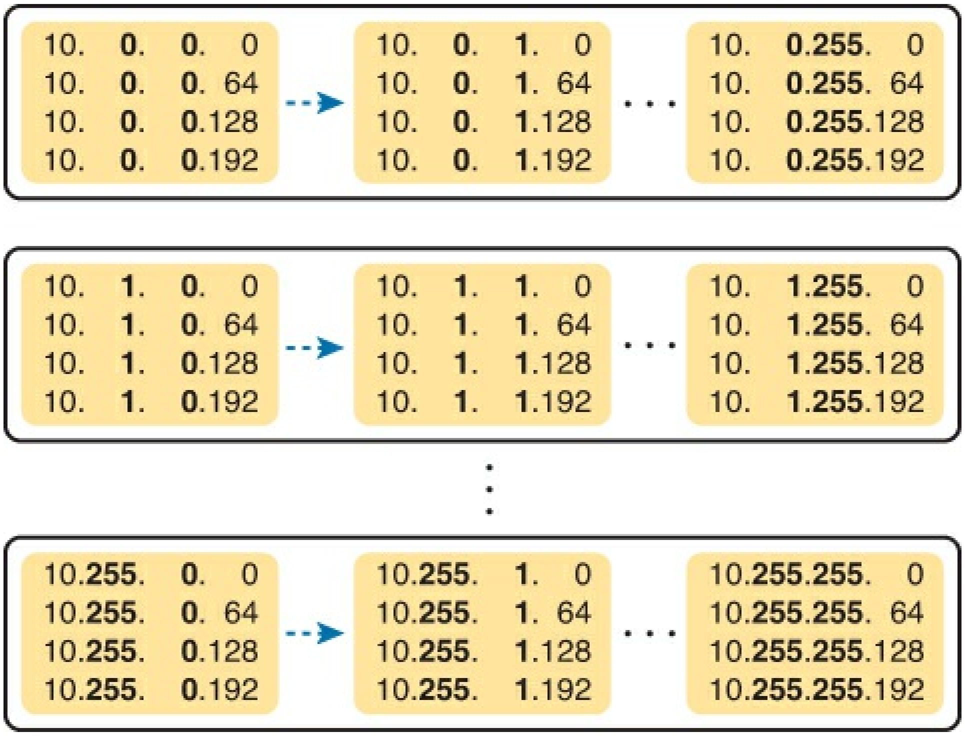


Figure 19-16. 256 Times 256 Subnet Blocks of Four Subnets

Practice Finding All Subnet IDs

Before moving to the next chapter, practice until you get the right answer most of the time—but use any tools you want and take all the time you need. Then, you can move on with your reading.

However, before taking the exam, practice until you master the topics in this chapter. Gauging a reasonable speed goal is difficult, because some combinations of network ID and mask can yield hundreds or thousands of subnets, while others can yield a much smaller number. So, for speed, before the exam, you should be able to do the first four subnets, which include the zero subnet, in 45 seconds. Table 19-5 summarizes the key concepts and suggestions for this two-phase approach.

Table 19-5. Keep-Reading and Take-Exam Goals for This Chapter's Topics

Time Frame	Before Moving to the Next Chapter	Before Taking the Exam
Focus On...	Learning how	Being correct and fast
Tools Allowed	All	Your brain and a notepad
Goal: Accuracy	90% correct	100% correct
Goal: Speed	Any speed	45 seconds

Practice Problems for Finding All Subnet IDs

The following list shows three separate problems, each with a classful network number and prefix-style mask. Find all subnet IDs for each problem:

1. 192.168.9.0/27
2. 172.30.0.0/20
3. 10.0.0.0/17

The section "Answers to Earlier Practice Problems," later in this chapter, lists the answers.

Additional Practice for Finding All Subnet IDs

This section lists several options for additional practice:

- Appendix G, "Practice for Chapter 19: Subnet Design," has some additional practice problems listed with explanations.
- Create your own problems. Some subnet calculators let you type an IP network and mask, and the calculator lists all the subnet IDs. Simply make up a network ID and mask, find the answer on paper, and then plug the values into the calculator to check your work.

- Watch the videos on the DVD that demonstrate the processes described in this chapter.

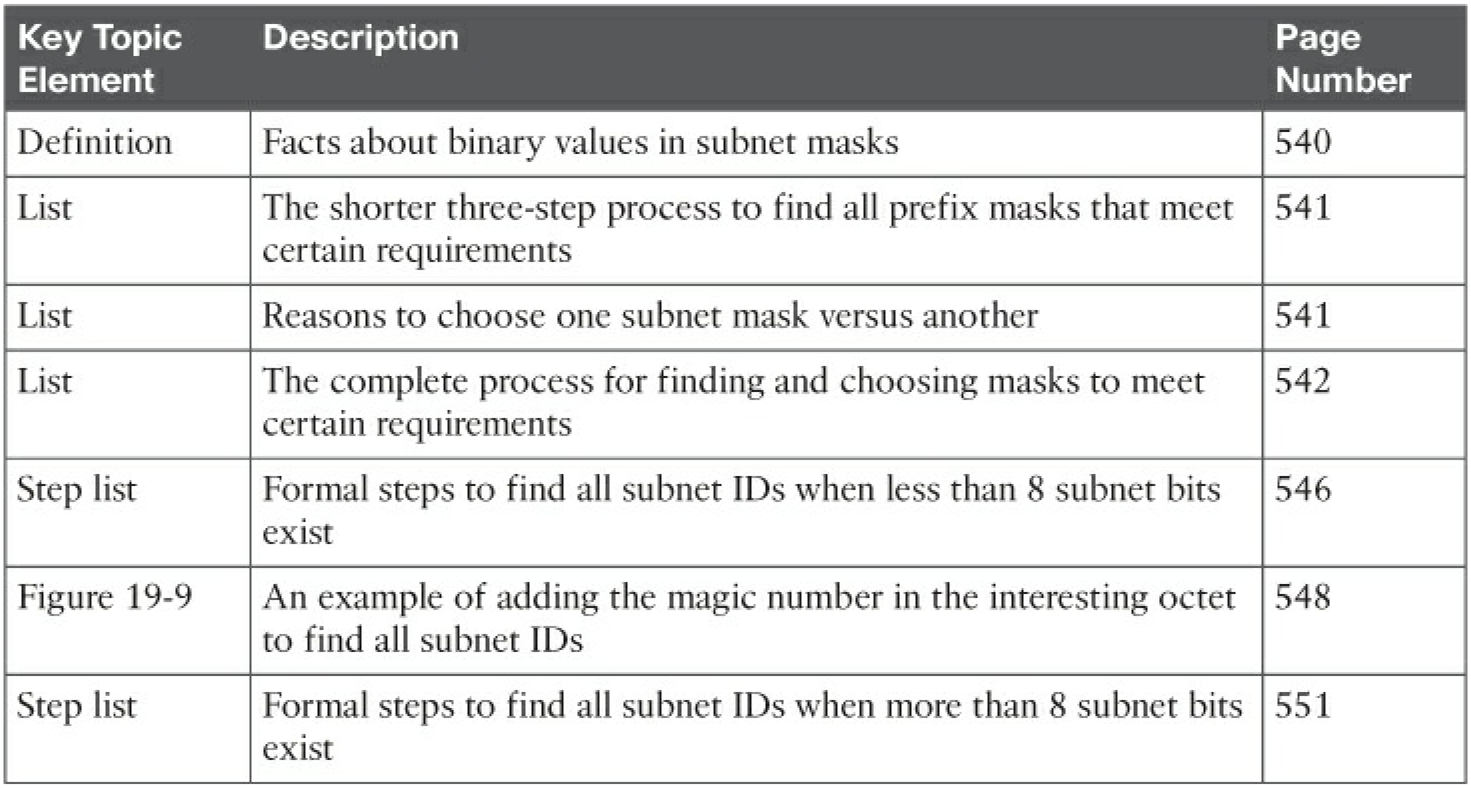
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 19-6 lists these key topics and where each is discussed.

Key Topic

Table 19-6. Key Topics for Chapter 19



Key Topic Element	Description	Page Number
Definition	Facts about binary values in subnet masks	540
List	The shorter three-step process to find all prefix masks that meet certain requirements	541
List	Reasons to choose one subnet mask versus another	541
List	The complete process for finding and choosing masks to meet certain requirements	542
Step list	Formal steps to find all subnet IDs when less than 8 subnet bits exist	546
Figure 19-9	An example of adding the magic number in the interesting octet to find all subnet IDs	548
Step list	Formal steps to find all subnet IDs when more than 8 subnet bits exist	551

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

zero subnet
subnet zero
broadcast subnet

Practice

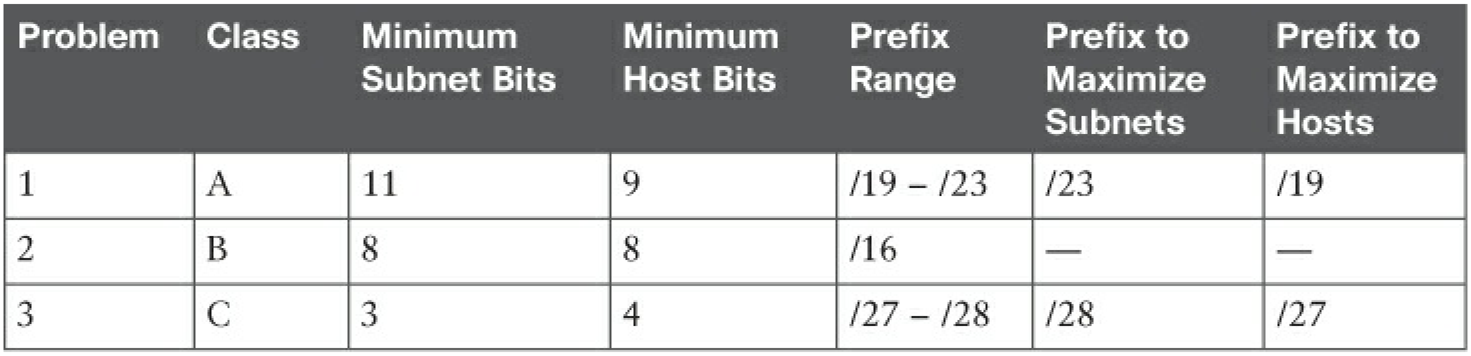
If you have not done so already, practice finding all subnet masks, based on requirements, as discussed in this chapter. Refer to the earlier section "Practice Choosing Subnet Masks" for suggestions.

Answers to Earlier Practice Problems

Answers to Practice Choosing Subnet Masks

The earlier section "Practice Choosing Subnet Masks" listed three practice problems. The answers are listed here so that the answers are nearby, but not visible from the list of problems. Table 19-7 lists the answers, with notes related to each problem following the table.

Table 19-7. Practice Problems: Find the Masks That Meet Requirements



Problem	Class	Minimum Subnet Bits	Minimum Host Bits	Prefix Range	Prefix to Maximize Subnets	Prefix to Maximize Hosts
1	A	11	9	/19 – /23	/23	/19
2	B	8	8	/16	—	—
3	C	3	4	/27 – /28	/28	/27

1. N=8, because the problem lists Class A network 10.0.0.0. With a need for 1500 subnets, 10 subnet bits supply only 1024 subnets (per Table 19-2), but 11 subnet bits (S) would provide 2048 subnets—more than the required 1500. Similarly, the smallest number of host bits would be 9, because $2^8 - 2 = 254$, and the design requires 300 hosts/subnet. The shortest prefix mask would then be /19, found by adding N (8) and the smallest usable number of subnet bits S (11). Similarly, with a minimum H value of 9, the longest prefix mask, maximizing the number of subnets, is 32 – H = /23.
2. N=16, because the problem lists Class B network 172.25.0.0. With a need for 130 subnets, 7 subnet bits supply only 128 subnets (per Table 19-2), but 8 subnet bits (S) would provide 256 subnets—more than the required 130. Similarly, the smallest number of host bits would be 8, because $2^7 - 2 = 126$—close to the required 127, but not quite enough, making H = 8 the smallest number of host bits that meets requirements. Note that the network, minimum subnet bits, and minimum host bits add up to 32, so only one mask meets the requirements, namely /24, found by adding the number of network bits (16) to the minimum number of subnet bits (8).
3. N=24, because the problem lists Class C network 192.168.83.0. With a need for eight subnets, 3 subnet bits supply enough, but just barely. The smallest number of host bits would be 4, because $2^3 - 2 = 6$, and the design requires 8 hosts/subnet. The shortest prefix mask would then be /27, found by adding N (24) and the smallest usable number of subnet bits S (3). Similarly, with a minimum H value of 4, the longest prefix mask, maximizing the number of subnets, is 32 – H = /28.

Answers to Practice Finding All Subnet IDs

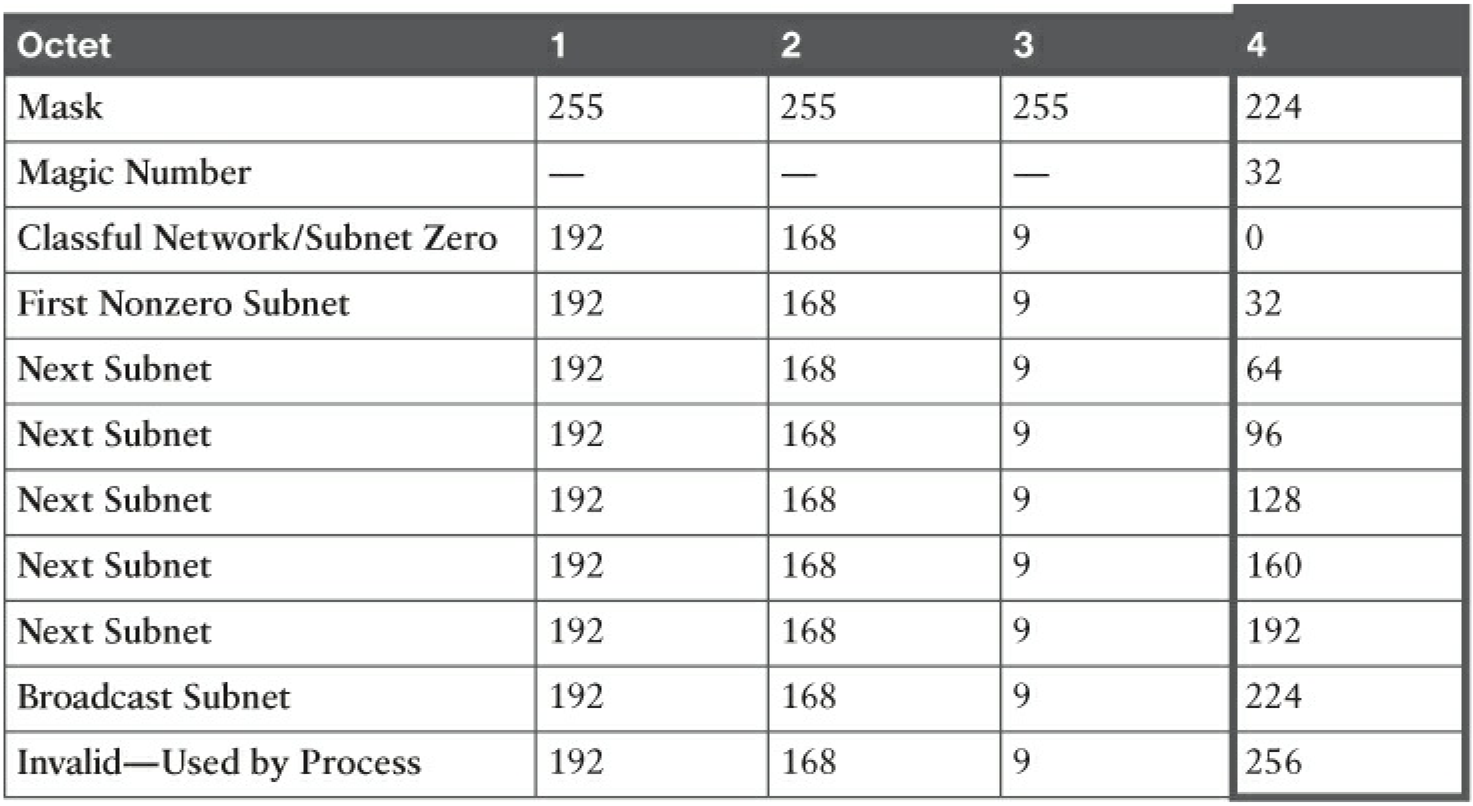
The earlier section "Practice Finding All Subnet IDs" listed three practice problems. The answers are listed here so that they are not visible from the same page as the list of problems.

Answer, Practice Problem 1

Problem 1 lists network 192.168.9.0, mask /27. The mask converts to DDN mask 255.255.255.224. When used with a Class C network, which has 24 network bits, only 3 subnet bits exist, and they all sit in the fourth octet. So, this problem is a case of less than 8 subnet bits, with the fourth octet as the interesting octet.

To get started listing subnets, first write down the zero subnet and then start adding the magic number in the interesting octet. The zero subnet equals the network ID (192.168.9.0, in this case). The magic number, calculated as 256 – 224 = 32, should be added to the previous subnet ID's interesting octet. Table 19-8 lists the results.

Table 19-8. List-All-Subnets Chart: 192.168.9.0/27



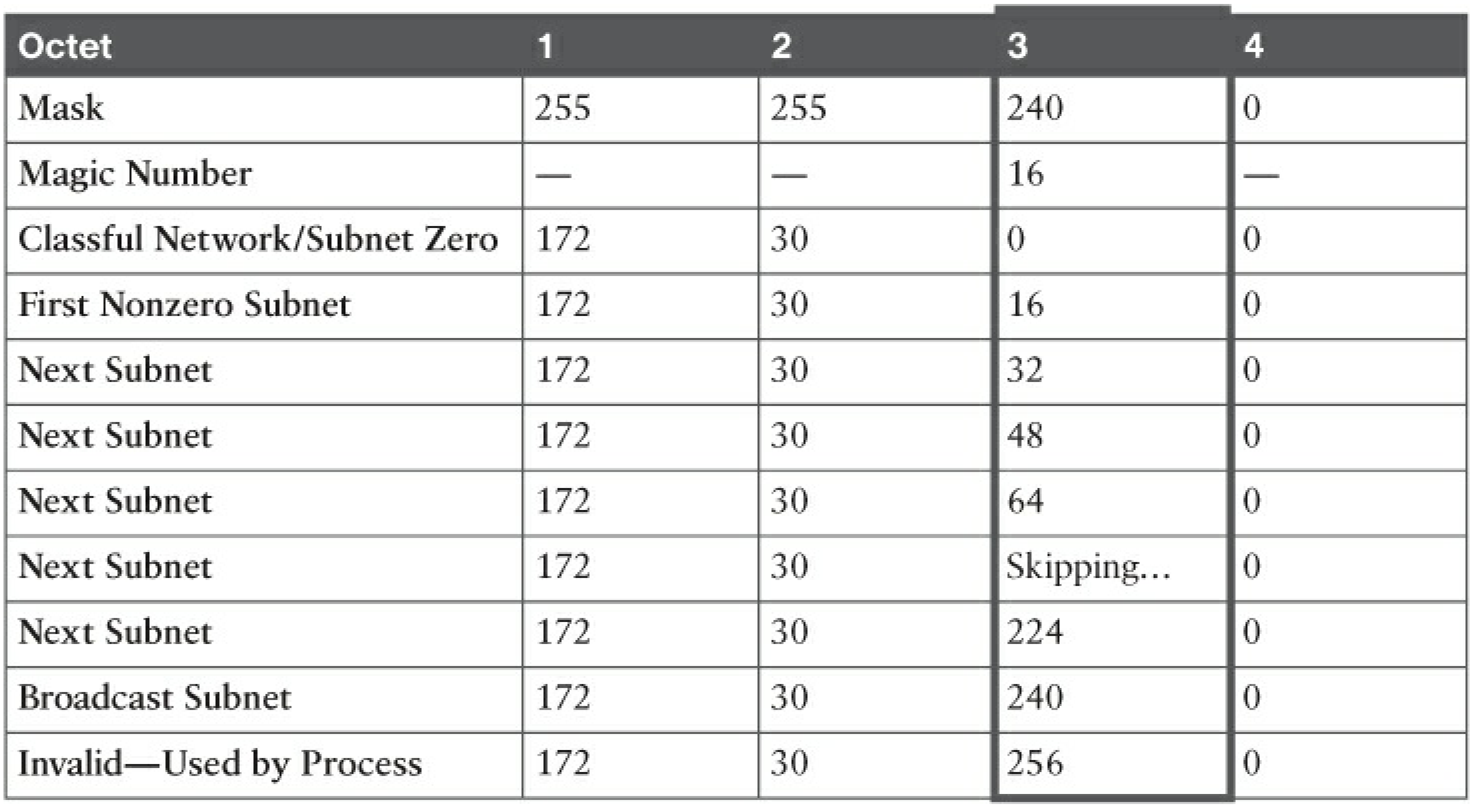
Octet	1	2	3	4
Mask	255	255	255	224
Magic Number	—	—	—	32
Classful Network/Subnet Zero	192	168	9	0
First Nonzero Subnet	192	168	9	32
Next Subnet	192	168	9	64
Next Subnet	192	168	9	96
Next Subnet	192	168	9	128
Next Subnet	192	168	9	160
Next Subnet	192	168	9	192
Broadcast Subnet	192	168	9	224
Invalid—Used by Process	192	168	9	256

Answer, Practice Problem 2

Problem 2 lists network 172.30.0.0, mask /20. The mask converts to DDN mask 255.255.240.0. When used with a Class B network, which has 16 network bits, only 4 subnet bits exist, and they all sit in the third octet. So, this problem is a case of less than 8 subnet bits, with the third octet as the interesting octet.

To get started listing subnets, first write down the zero subnet and then start adding the magic number in the interesting octet. The zero subnet equals the network ID (or 172.30.0.0, in this case). The magic number, calculated as 256 – 240 = 16, should be added to the previous subnet ID's interesting octet. Table 19-9 lists the results.

Table 19-9. List-All-Subnets Chart: 172.30.0.0/2



Octet	1	2	3	4
Mask	255	255	240	0
Magic Number	—	—	16	—
Classful Network/Subnet Zero	172	30	0	0
First Nonzero Subnet	172	30	16	0
Next Subnet	172	30	32	0
Next Subnet	172	30	48	0
Next Subnet	172	30	64	0
Next Subnet	172	30	Skipping...	0
Next Subnet	172	30	224	0
Broadcast Subnet	172	30	240	0
Invalid—Used by Process	172	30	256	0

Answer, Practice Problem 3

Problem 3 lists network 10.0.0.0, mask /17. The mask converts to DDN mask 255.255.128.0. When used with a Class A network, which has 8 network bits, 9 subnet bits exist. Using the terms unique to this chapter, octet 3 is the interesting octet, with only 1 subnet bit in that octet, and octet 2 is the just-left octet, with 8 subnet bits.

In this case, begin by finding the first subnet block. The magic number is 256 – 128 = 128. The first subnet (zero subnet) equals the network ID. So, the first subnet ID block includes the following:

10.0.0.0
10.0.128.0

Then, you create a subnet block for all 256 possible values in the just-left octet, or octet 2 in this case. The following list shows the first three subnet ID blocks, plus the last subnet ID block, rather than listing page upon page of subnet IDs:

10.0.0.0 (zero subnet)
10.0.128.0
10.1.0.0
10.1.128.0
10.2.0.0
10.2.128.0
...
10.255.0.0
10.255.128.0 (broadcast subnet)

Chapter 20. Variable-Length Subnet Masks

This chapter covers the following exam topics:

IP addressing (IPv4/IPv6)

Identify the appropriate IPv4 addressing scheme using VLSM and summarization to satisfy addressing requirements in a LAN/WAN environment.

Troubleshooting

Troubleshoot and correct common problems associated with IP addressing and host configurations.

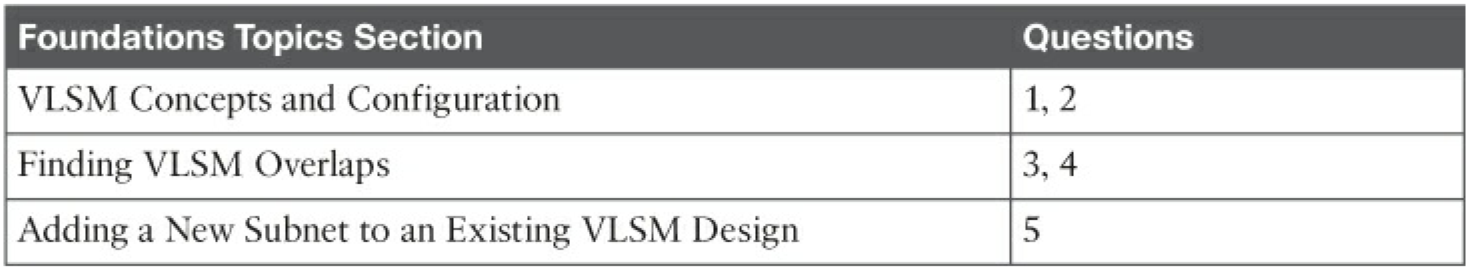
IPv4 addressing and subnetting use a lot of terms, a lot of small math steps, and a lot of concepts that fit together. While learning those concepts, it helps to keep things as simple as possible. One way this book has kept the discussion simpler so far was to show examples that use one mask only inside a single Class A, B, or C network.

This chapter removes that restriction by introducing variable-length subnet masks (VLSM). VLSM simply means that the subnet design uses more than one mask in the same classful network. VLSM has some advantages and disadvantages, but when learning, the main challenge is that a subnetting design that uses VLSM requires more math, and it requires that you think about some other issues as well. This chapter walks you through the concepts, the issues, and the math.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 20-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundations Topics Section	Questions
VLSM Concepts and Configuration	1, 2
Finding VLSM Overlaps	3, 4
Adding a New Subnet to an Existing VLSM Design	5

1. Which of the following routing protocols support VLSM? (Choose three answers.)
   - **a.** RIP-1
   - **b.** RIP-2
   - **c.** EIGRP
   - **d.** OSPF
2. What does the acronym VLSM stand for?
   - **a.** Variable-length subnet mask
   - **b.** Very long subnet mask
   - **c.** Vociferous longitudinal subnet mask
   - **d.** Vector-length subnet mask
   - **e.** Vector loop subnet mask
3. R1 has configured interface Fa0/0 with the **ip address 10.5.48.1 255.255.240.0** command. Which of the following subnets, when configured on another interface on R1, would not be considered an overlapping VLSM subnet?
   - **a.** 10.5.0.0 255.255.240.0
   - **b.** 10.4.0.0 255.254.0.0
   - **c.** 10.5.32.0 255.255.224.0
   - **d.** 10.5.0.0 255.255.128.0
4. R4 has a connected route for 172.16.8.0/22. Which of the following answers lists a subnet that overlaps with this subnet?
   - **a.** 172.16.0.0/21
   - **b.** 172.16.6.0/23
   - **c.** 172.16.16.0/20
   - **d.** 172.16.11.0/25
5. A design already includes subnets 192.168.1.0/26, 192.168.1.128/30, and 192.168.1.160/29. Which of the following subnets is the numerically lowest subnet ID that could be added to the design, if you wanted to add a subnet that uses a /28 mask?

- **a.** 192.168.1.144/28
- **b.** 192.168.1.112/28
- **c.** 192.168.1.64/28
- **d.** 192.168.1.80/28
- **e.** 192.168.1.96/28

Answers to the "Do I Know This Already?" quiz:

1 B, C, and D **2** A **3** A **4** D **5** C

Foundation Topics

VLSM Concepts and Configuration

VLSM occurs when an internetwork uses more than one mask for different subnets of a single Class A, B, or C network. Figure 20-1 shows an example of VLSM used in Class A network 10.0.0.0.

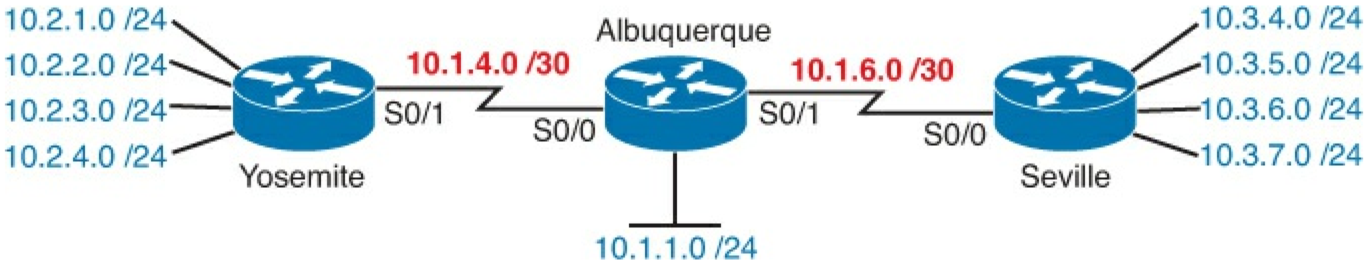


Figure 20-1. VLSM in Network 10.0.0.0: Masks *24 and* 30

Figure 20-1 shows a typical choice of using a *30 prefix (mask 255.255.255.252) on point-to-point serial links, with mask* 24 (255.255.255.0) on the LAN subnets. All subnets are of Class A network 10.0.0.0, with two masks being used, therefore meeting the definition of VLSM.

Oddly enough, a common mistake occurs when people think that VLSM means "using more than one mask in some internetwork" rather than "using more than one mask *in a single classful network*." For example, if in one internetwork diagram, all subnets of network 10.0.0.0 use a 255.255.240.0 mask, and all subnets of network 11.0.0.0 use a 255.255.255.0 mask, the design uses two different masks. However, Class A network 10.0.0.0 uses only one mask, and Class A network 11.0.0.0 uses only one mask. In that case, the design does not use VLSM.

VLSM provides many benefits for real networks, mainly related to how you allocate and use your IP address space. Because a mask defines the size of the subnet (the number of host addresses in the subnet), VLSM allows engineers to better match the need for addresses with the size of the subnet. For example, for subnets that need fewer addresses, the engineer uses a mask with fewer host bits, so the subnet has fewer host IP addresses. This flexibility reduces the number of wasted IP addresses in each subnet. By wasting fewer addresses, more space remains to allocate more subnets.

VLSM can be helpful for both public and private IP addresses, but the benefits are more dramatic with public networks. With public networks, the address savings help engineers avoid having to obtain another registered IP network number from regional IP address assignment authorities. With private networks, as defined in RFC 1918, running out of addresses is not as big a negative, because you can always grab another private network from RFC 1918 if you run out.

Classless and Classful Routing Protocols

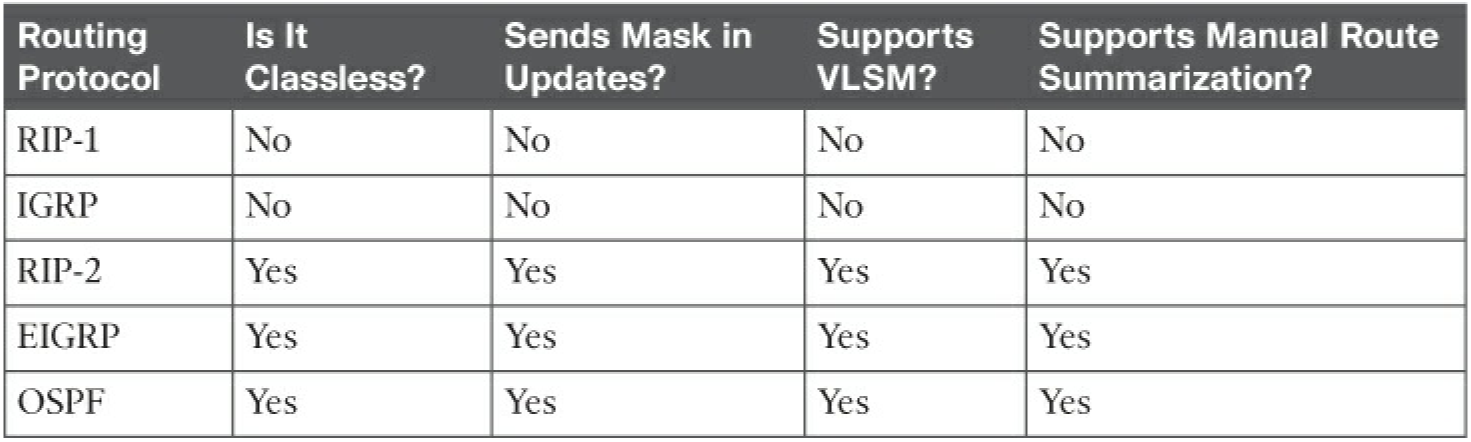
Before you can deploy a VLSM design created on paper, you must first use a routing protocol that supports VLSM. To support VLSM, the routing protocol must advertise the mask along with each subnet. Without mask information, the router receiving the update would be confused.

For example, if a router learned a route for 10.1.8.0, but with no mask information, what does that mean? Is that subnet 10.1.8.0/24? 10.1.8.0/23? 10.1.8.0/30? The dotted-decimal number 10.1.8.0 happens to be a valid subnet number with a variety of masks, and because multiple masks can be used with VLSM, the router has no good way to make an educated guess. To effectively support VLSM, the routing protocol needs to advertise the correct mask along with each subnet so that the receiving router knows the exact subnet that is being advertised.

By definition, *classless routing protocols* advertise the mask with each advertised route, and *classful routing protocols* do not. The classless routing protocols, as noted in Table 20-2, are the newer, more advanced routing protocols. And not only do these more advanced classless routing protocols support VLSM, but they also support manual route summarization, a feature discussed in Chapter 21, "Route Summarization."

Key Topic

Table 20-2. Classless and Classful Interior IP Routing Protocols



Routing Protocol	Is It Classless?	Sends Mask in Updates?	Supports VLSM?	Supports Manual Route Summarization?
RIP-1	No	No	No	No
IGRP	No	No	No	No
RIP-2	Yes	Yes	Yes	Yes
EIGRP	Yes	Yes	Yes	Yes
OSPF	Yes	Yes	Yes	Yes

Beyond VLSM itself, the routing protocols do not have to be configured to support VLSM or to be classless. There is no command to enable or disable the fact that classless routing protocols include the mask with each route. The only configuration choice you must make is to use a classless routing protocol, which among the routing protocols discussed for CCENT and CCNA are EIGRP and OSPF.

VLSM Configuration and Verification

Cisco routers do not configure VLSM, enable or disable it, or need any configuration to use it. From a configuration perspective, VLSM is simply a side effect of using the **ip address** interface subcommand. Routers collectively configure VLSM by virtue of having IP addresses in the same classful network but with different masks.

For example, Example 20-1 shows two of the interfaces from router Yosemite from Figure 20-1. The example shows the IP address assignments on two interfaces, one with a *24 mask and one with a* 30 mask, both with IP addresses in Class A network 10.0.0.0.

Example 20-1. Configuring Two Interfaces on Yosemite, Resulting in VLSM

Click here to view code image

```
Yosemite# configure terminal
Yosemite(config)# interface Fa0/0
Yosemite(config-if)# ip address 10.2.1.1 255.255.255.0
Yosemite(config-if)# interface S0/1
Yosemite(config-if)# ip address 10.1.4.1 255.255.255.252
```

The use of VLSM can also be detected by a detailed look at the output of the **show ip route** command. This command lists routes in groups, by classful network, so that you see all the subnets of a single Class A, B, or C network all in a row. Just look down the list, and look to see, if any, how many different masks are listed. For example, Example 20-2 lists the routing table on Albuquerque from Figure 20-1; Albuquerque uses masks *24 and* 30 inside network 10.0.0.0, as noted in the highlighted line in the example.

Example 20-2. Albuquerque Routing Table with VLSM

Click here to view code image

```
Albuquerque# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
E1 - OSPF external type 1, E2 - OSPF external type 2
i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
ia - IS-IS inter area, * - candidate default, U - per-user static route
```

```
o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
+ - replicated route, % - next hop override

Gateway of last resort is not set

10.0.0.0/8 is variably subnetted, 14 subnets, 3 masks
D 10.2.1.0/24 [90/2172416] via 10.1.4.1, 00:00:34, Serial0/0
D 10.2.2.0/24 [90/2172416] via 10.1.4.1, 00:00:34, Serial0/0
D 10.2.3.0/24 [90/2172416] via 10.1.4.1, 00:00:34, Serial0/0
D 10.2.4.0/24 [90/2172416] via 10.1.4.1, 00:00:34, Serial0/0
D 10.3.4.0/24 [90/2172416] via 10.1.6.2, 00:00:56, Serial0/1
D 10.3.5.0/24 [90/2172416] via 10.1.6.2, 00:00:56, Serial0/1
D 10.3.6.0/24 [90/2172416] via 10.1.6.2, 00:00:56, Serial0/1
D 10.3.7.0/24 [90/2172416] via 10.1.6.2, 00:00:56, Serial0/1
C 10.1.1.0/24 is directly connected, FastEthernet0/0
L 10.1.1.1/32 is directly connected, FastEthernet0/0
C 10.1.6.0/30 is directly connected, Serial0/1
L 10.1.6.1/32 is directly connected, Serial0/1
C 10.1.4.0/30 is directly connected, Serial0/0
L 10.1.4.1/32 is directly connected, Serial0/0
```

Note

For the purposes of understanding whether a design uses VLSM, ignore the /32 "local" routes that a router automatically creates for its own interface IP addresses.

So ends the discussion of VLSM as an end to itself. This chapter is devoted to VLSM, but it took a mere three to four pages to fully describe it. Why the entire VLSM chapter? Well, to work with VLSM, to find problems with it, to add subnets to an existing design, and to design using VLSM from scratch—in other words, to apply VLSM to real networks—takes skill and practice. To do these same tasks on the exam requires skill and practice. The rest of this chapter examines the skills to apply VLSM and provides some practice for these two key areas:

- Finding VLSM overlaps
- Adding new VLSM subnets without overlaps

Finding VLSM Overlaps

Regardless of whether a design uses VLSM, the subnets used in any IP internetwork design should not overlap their address ranges. When subnets in different locations overlap their addresses, a router's routing table entries overlap. As a result, hosts in different locations can be assigned the same IP address. Routers clearly cannot route packets correctly in these cases. In short, a design that uses overlapping subnets is considered to be an incorrect design and should not be used.

Note

Although I've not seen the term used in other places, just to have a term to contrast with VLSM, this book refers to the non-use of VLSM—in other words, using a single mask throughout a classful network—as static-length subnet masks (SLSM).

These address overlaps are easier to see when using SLSM than when using VLSM. With SLSM, overlapped subnets have identical subnet IDs, so to find overlaps, you just have to look at the subnet IDs. With VLSM, overlapped subnets cannot have the same subnet ID. To find these overlaps, you have to look at the entire range of addresses in each subnet, from subnet ID to subnet broadcast address, and compare the range to the other subnets in the design.

An Example of Finding a VLSM Overlap

For example, imagine that a practice question for the CCENT exam shows Figure 20-2. It uses a single Class B network (172.16.0.0), with VLSM, because it uses three different masks: /23, *24, and* 30.

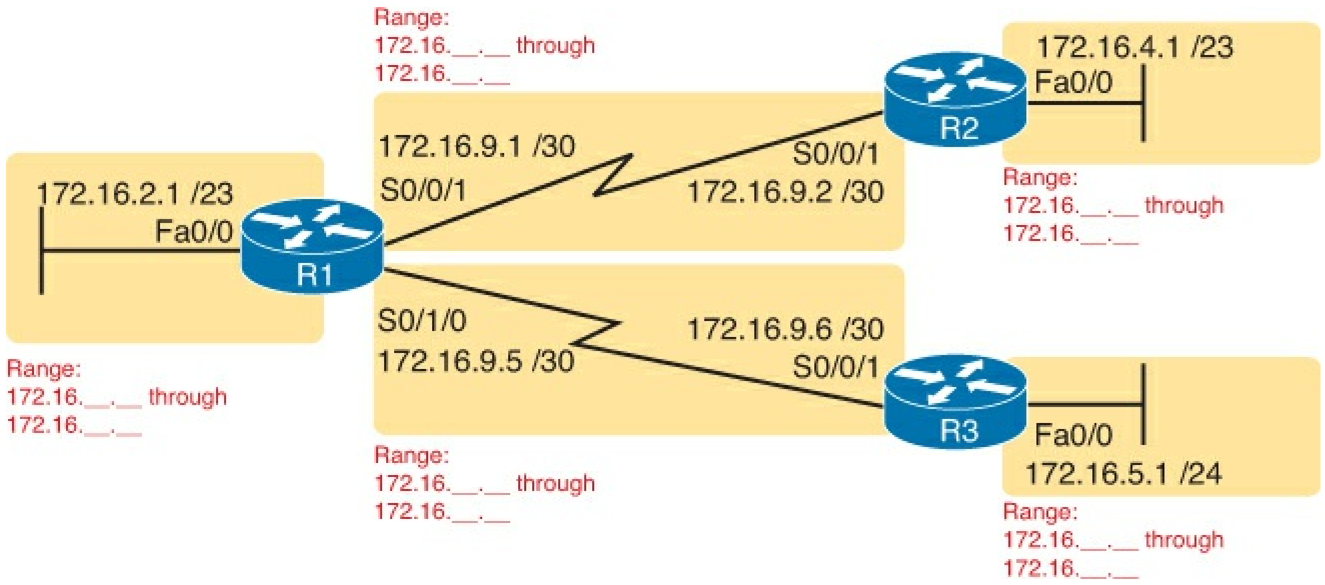


Figure 20-2. VLSM Design with Possible Overlap

Now imagine that the exam question shows you the figure, and either directly or indirectly asks whether overlapping subnets exist. This type of question might simply tell you that some hosts cannot ping each other, or it might not even mention that the root cause could be that some of the subnets overlap. To answer such a question, you could follow this simple but possibly laborious process:

Key Topic

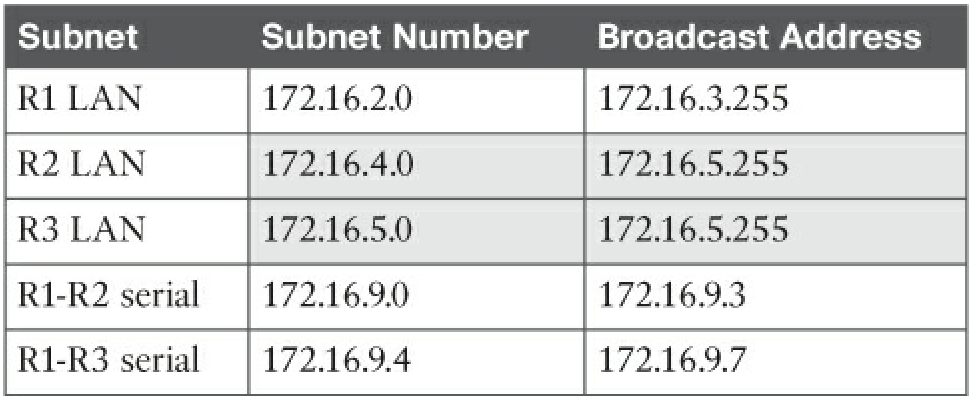
Step 1. Calculate the subnet ID and subnet broadcast address of each subnet, which gives you the range of addresses in that subnet.

Step 2. List the subnet IDs in numerical order (along with their subnet broadcast addresses).

Step 3. Scan the list from top to bottom, comparing each pair of adjacent entries, to see whether their range of addresses overlaps.

For example, Table 20-3 completes the first two steps based on Figure 20-2, listing the subnet IDs and subnet broadcast addresses, in numerical order based on the subnet IDs.

Table 20-3. Subnet IDs and Broadcast Addresses, in Numerical Order, from Figure 20-2



Subnet	Subnet Number	Broadcast Address
R1 LAN	172.16.2.0	172.16.3.255
R2 LAN	172.16.4.0	172.16.5.255
R3 LAN	172.16.5.0	172.16.5.255
R1-R2 serial	172.16.9.0	172.16.9.3
R1-R3 serial	172.16.9.4	172.16.9.7

Step 3 states the somewhat obvious step of comparing the address ranges to see whether any overlaps occur. You could just scan the list overall, but if you order the list, you can also methodically scan the list looking at each adjacent pair.

First, look closely just at the subnet number column in Table 20-3. Note that, in this case, none of the subnet numbers are identical, but two entries (highlighted) do overlap.

Next, look closely at the R2 LAN and R3 LAN subnets. All the addresses in the 172.16.5.0/24 subnet are also part of the 172.16.4.0/23 subnet. In this case, the design is invalid because of the overlap, and one of these two subnets would need to be changed.

As far as the three-step process works, note that if two adjacent entries in the list overlap, compare three entries at the next step. The two subnets already marked as overlapped can overlap with the next subnet in the list. For example, imagine a case where you had the following three subnets in a list that you were examining for VLSM overlaps:

10.1.0.0/16 (subnet ID 10.1.0.0, broadcast 10.1.255.255)

10.1.200.0/24 (subnet ID 10.1.200.0, broadcast 10.1.200.255)

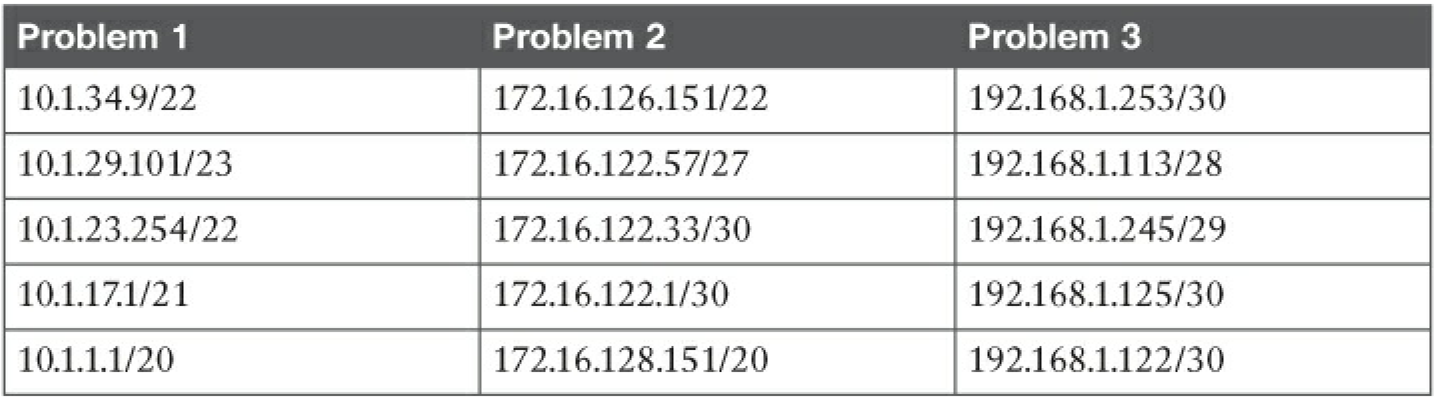
10.1.250.0/24 (subnet ID 10.1.250.0, broadcast 10.1.250.255)

If you compare entries 1 and 2, clearly an overlap occurs, because all the addresses in subnet 10.1.200.0/24 sit inside subnet 10.1.0.0/16. If you then compare only entries 2 and 3, those entries do not overlap. However, entries 1 and 3 do overlap. So what does this mean for the process? Anytime you find an overlap, compare all those overlapped subnets with the next line in the list of subnets until you find one that doesn't overlap.

Practice Finding VLSM Overlaps

As typical of anything to with applying IP addressing and subnetting, practice helps. To that end, Table 20-4 lists three practice problems. Just start with the five IP addresses listed in a single column, and then follow the three-step process outlined in the previous section to find any VLSM overlaps. The answers can be found near the end of this chapter, in the section "Answers to Earlier Practice Problems."

Table 20-4. VLSM Overlap Practice Problems



Problem 1	Problem 2	Problem 3
10.1.34.9/22	172.16.126.151/22	192.168.1.253/30
10.1.29.101/23	172.16.122.57/27	192.168.1.113/28
10.1.23.254/22	172.16.122.33/30	192.168.1.245/29
10.1.17.1/21	172.16.122.1/30	192.168.1.125/30
10.1.1.1/20	172.16.128.151/20	192.168.1.122/30

Adding a New Subnet to an Existing VLSM Design

The task described in this section happens frequently in real networks: choosing new subnets to add to an existing design. In real life, you can use tools that help you choose a new subnet so that you do not cause an overlap. However, for both real life and for the CCENT and CCNA exams, you need to be ready to do the mental process and math of choosing a subnet that both has the right number of host IP addresses and does not create an overlapped VLSM subnet condition. In other words, you need to pick a new subnet and not make a mistake!

For example, consider the internetwork shown earlier in Figure 20-2, with classful network 172.16.0.0. An exam question might suggest that a new subnet, with a /23 prefix length, needs to be added to the design. The question might also say, "Pick the numerically lowest subnet number that can be used for the new subnet." In other words, if both 172.16.4.0 and 172.16.6.0 would work, use 172.16.4.0.

So, you really have a couple of tasks: To find all the subnet IDs that could be used, rule out the ones that would cause an overlap, and then check to see whether the question guides you to pick either the numerically lowest (or highest) subnet ID. This list outlines the specific steps:

Key Topic

Step 1. Pick the subnet mask (prefix length) for the new subnet, based on the design requirements (if not already listed as part of the question).

Step 2. Calculate all possible subnet numbers of the classful network using the mask from Step 1, along with the subnet broadcast addresses.

Step 3. Make a list of existing subnet IDs and matching subnet broadcast addresses.

Step 4. Rule out overlapping new subnets by comparing the lists from the previous two steps.

Step 5. Choose the new subnet ID from the remaining subnets identified at Step 4, paying attention to whether the question asks for the numerically lowest or numerically highest subnet ID.

An Example of Adding a New VLSM Subnet

For example, Figure 20-3 shows an existing internetwork that uses VLSM. (The figure uses the same IP addresses as shown in Figure 20-2, but with R3's LAN IP address changed to fix the VLSM overlap shown in Figure 20-2.) In this case, you need to add a new subnet to support 300 hosts. Imagine that the question tells you to use the smallest subnet (least number of hosts) to meet that requirement. You use some math and logic you learned earlier in your study to choose mask /23, which gives you 9 host bits, for $2^9 - 2 = 510$ hosts in the subnet.

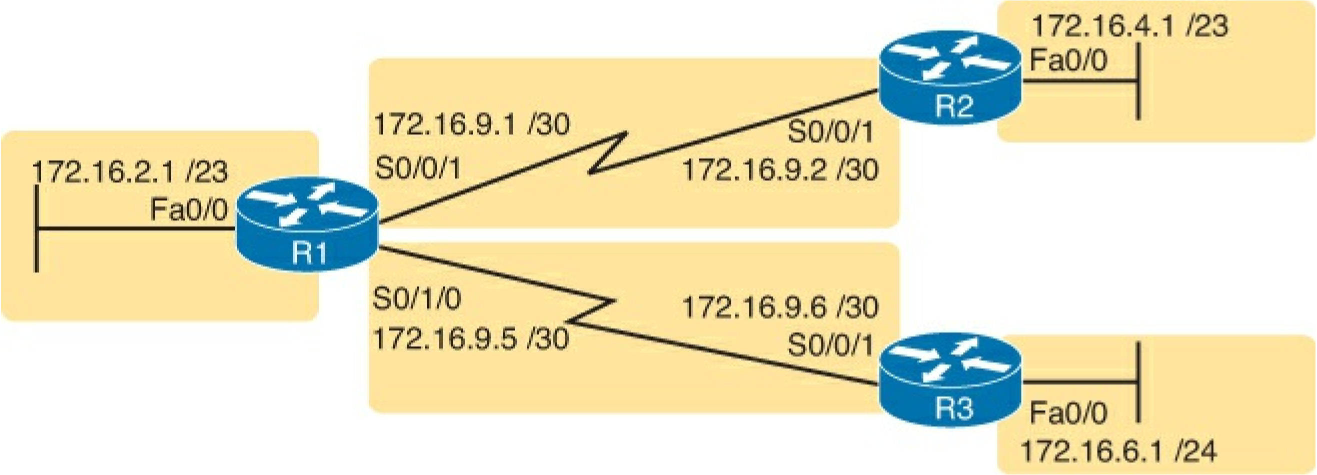
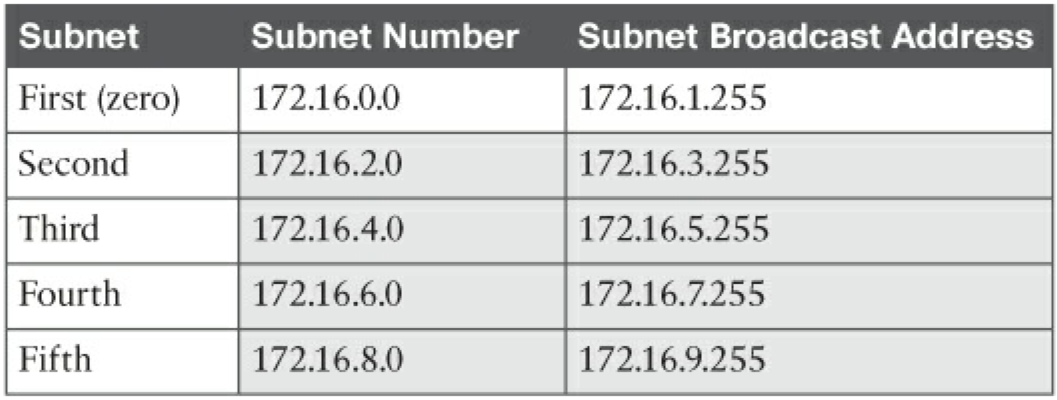


Figure 20-3. Internetwork to Which You Need to Add a /23 Subnet, Network 172.16.0.0

> **Note**
>
> If the logic and process in the previous paragraph were unfamiliar, it might be useful to take some time to review Chapter 19, "Subnet Design."

At this point, just follow the steps listed before Figure 20-3. For Step 1, you have already been given the mask (/23). For Step 2, you need to list all the subnet numbers and broadcast addresses of 172.16.0.0, assuming the /23 mask. You will not use all these subnets, but you need the list for comparison to the existing subnets. Table 20-5 shows the results, at least for the first five possible /23 subnets.

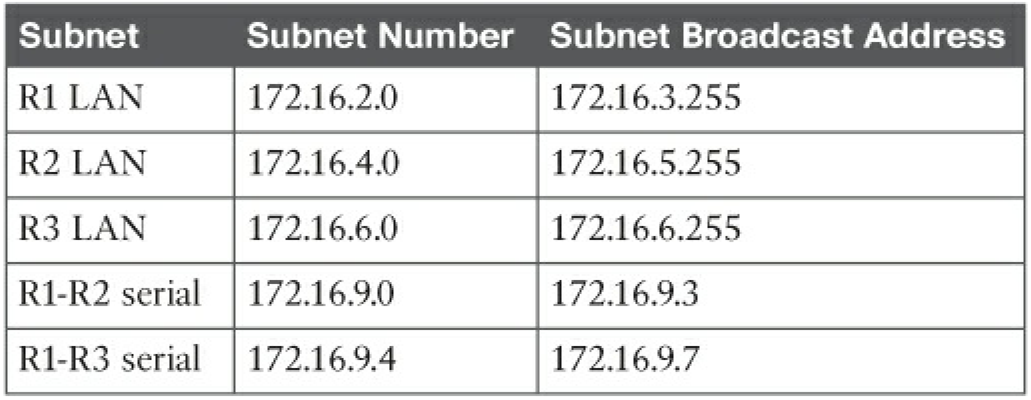
Table 20-5. First Five Possible /23 Subnets



Subnet	Subnet Number	Subnet Broadcast Address
First (zero)	172.16.0.0	172.16.1.255
Second	172.16.2.0	172.16.3.255
Third	172.16.4.0	172.16.5.255
Fourth	172.16.6.0	172.16.7.255
Fifth	172.16.8.0	172.16.9.255

Next, at Step 3, list the existing subnet numbers and broadcast addresses, as seen earlier in Figure 20-3. To do so, do the usual math to take an IP address/mask to then find the subnet ID and subnet broadcast address. Table 20-6 summarizes that information, including the locations, subnet numbers, and subnet broadcast addresses.

Table 20-6. Existing Subnet IDs and Broadcast Addresses from Figure 20-3



Subnet	Subnet Number	Subnet Broadcast Address
R1 LAN	172.16.2.0	172.16.3.255
R2 LAN	172.16.4.0	172.16.5.255
R3 LAN	172.16.6.0	172.16.6.255
R1-R2 serial	172.16.9.0	172.16.9.3
R1-R3 serial	172.16.9.4	172.16.9.7

At this point, you have all the information you need to look for the overlap at Step 4. Simply compare the range of numbers for the subnets in the previous two tables. Which of the possible new /23 subnets (Table 20-5) overlap with the existing subnets (Table 20-6)? In this case, the second, third, and fifth subnets in Table 20-5 overlap, so rule those out as candidates to be used. (Table 20-5 denotes those subnets with gray highlights.)

Step 5 has more to do with the exam than with real network design, but it is still worth listing as a separate step. Multiple-choice questions sometimes need to force you into a single answer, and asking for the numerically lowest or highest subnet does that. This particular example asks for the numerically lowest subnet number, which in this case is 172.16.0.0/23.

> **Note**
>
> The answer, 172.16.0.0/23, happens to be a zero subnet. For the exam, the zero subnet should be avoided if (a) the question implies the use of classful routing protocols or (b) the routers are configured with the **no ip subnet-zero** global configuration command. Otherwise, assume that the zero subnet can be used.

Practice Adding New VLSM Subnets

Your boss wants you to add one subnet to an existing design. The existing design already has these five subnets:

10.0.0.0/24
10.0.1.0/25
10.0.2.0/26
10.0.3.0/27
10.0.6.0/28

The boss cannot decide among five competing subnet masks to use for this next new subnet to add to the internetwork. However, the boss wants you to practice VLSM and plan the subnet ID that he would use for each of those four possible masks. He tells you that the new subnet ID must be part of Class A network 10.0.0.0, that the new subnet must not overlap with the original five subnets, and that the new subnet ID must be the numerically lowest possible subnet ID (without breaking the other rules). Pick the one subnet ID that you would plan to use based on each of the following mask choices by the boss:

1. /24
2. /23
3. /22
4. /25

You can find the answers in the section "Answers to Earlier Practice Problems," later in this chapter.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 20-7 lists these key topics and where each is discussed.

Key Topic

Table 20-7. Key Topics for Chapter 20

Key Topic Element	Description	Page Number
Table 20-2	Classless and classful routing protocols listed and compared	564
List	Steps to analyze an existing design to discover any VLSM overlaps	567
List	Steps to follow when adding a new subnet to an existing VLSM design	569

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

- classful routing protocol
- classless routing protocol
- overlapping subnets
- variable-length subnet masks (VLSM)

Appendix H Practice Problems

DVD Appendix H, "Practice for Chapter 20: Variable-Length Subnet Masks," lists additional practice problems and answers.

Answers to Earlier Practice Problems

Answers to Practice Finding VLSM Overlaps

This section lists the answers to the three practice problems in the section "Practice Finding VLSM Overlaps," as listed earlier in Table 20-4. Note that the tables that list details of the answer reordered the subnets as part of the process.

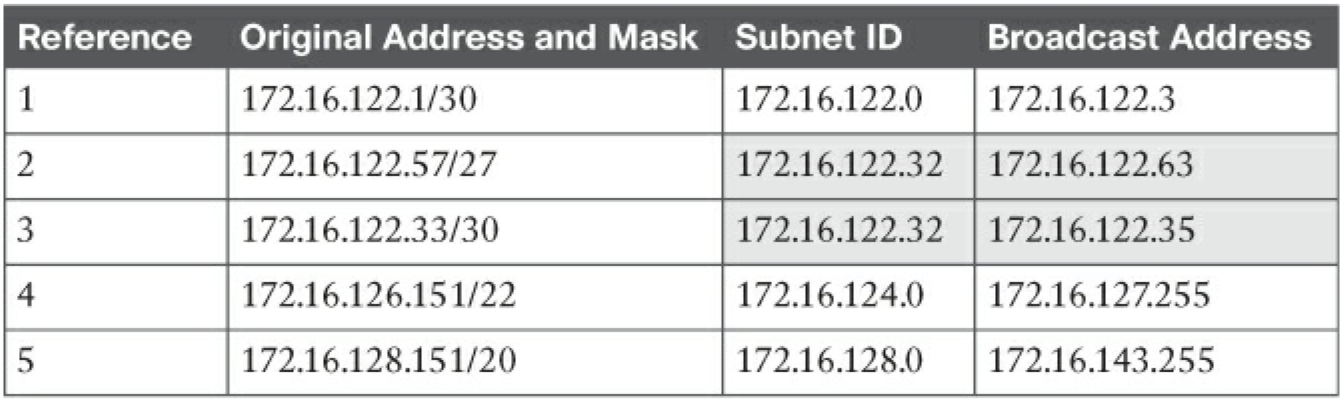
In Problem 1, the second and third subnet IDs listed in Table 20-8 happen to overlap. The second subnet's range completely includes the range of addresses in the third subnet.

Table 20-8. VLSM Overlap Problem 1 Answers (Overlaps Highlighted)

Reference	Original Address and Mask	Subnet ID	Broadcast Address
1	10.1.1.1/20	10.1.0.0	10.1.15.255
2	10.1.17.1/21	10.1.16.0	10.1.23.255
3	10.1.23.254/22	10.1.20.0	10.1.23.255
4	10.1.29.101/23	10.1.28.0	10.1.29.255
5	10.1.34.9/22	10.1.32.0	10.1.35.255

In Problem 2, again the second and third subnet IDs (listed in Table 20-9) happen to overlap, and again, the second subnet's range completely includes the range of addresses in the third subnet. Also, the second and third subnet IDs are the same value, so the overlap is more obvious.

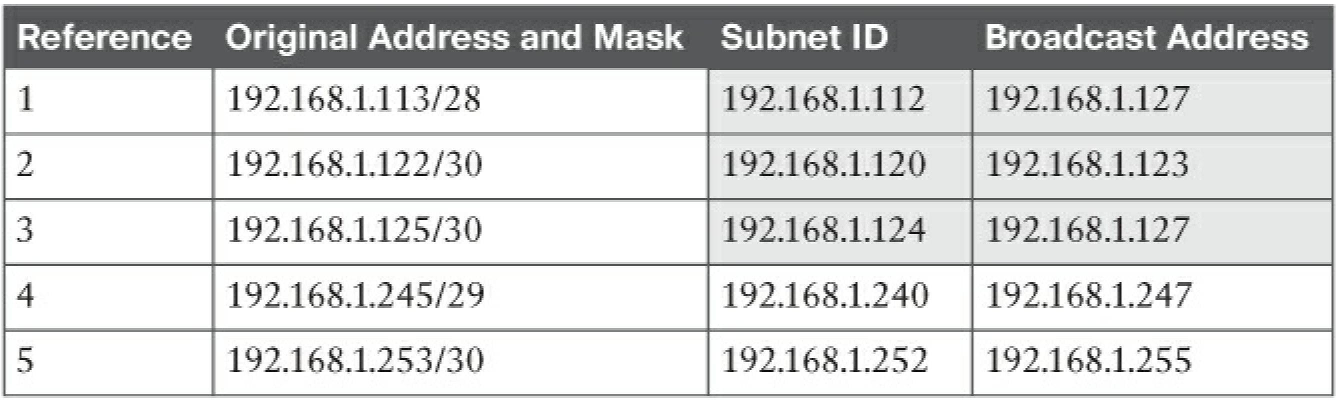
Table 20-9. VLSM Overlap Problem 2 Answers (Overlaps Highlighted)



Reference	Original Address and Mask	Subnet ID	Broadcast Address
1	172.16.122.1/30	172.16.122.0	172.16.122.3
2	172.16.122.57/27	172.16.122.32	172.16.122.63
3	172.16.122.33/30	172.16.122.32	172.16.122.35
4	172.16.126.151/22	172.16.124.0	172.16.127.255
5	172.16.128.151/20	172.16.128.0	172.16.143.255

In Problem 3, three subnets overlap. Subnet 1's range completely includes the range of addresses in the second and third subnets, as shown in Table 20-10. Note that the second and third subnets do not overlap with each other, so for the process in this book to find all the overlaps, after you find that the first two subnets overlap, you should compare the next entry in the table (3) with both of the two known-to-overlap entries (1 and 2).

Table 20-10. VLSM Overlap Problem 3 Answers (Overlaps Highlighted)

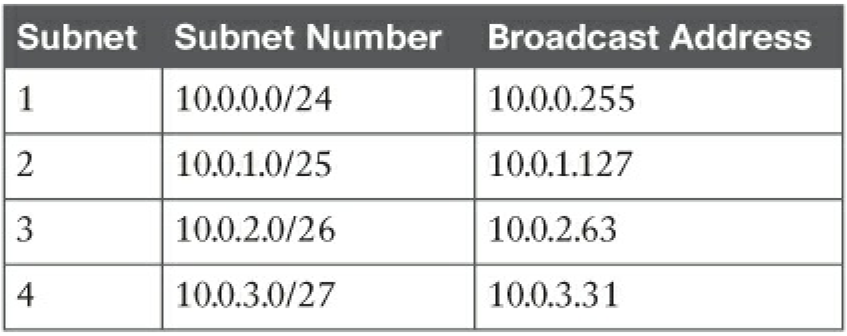


Reference	Original Address and Mask	Subnet ID	Broadcast Address
1	192.168.1.113/28	192.168.1.112	192.168.1.127
2	192.168.1.122/30	192.168.1.120	192.168.1.123
3	192.168.1.125/30	192.168.1.124	192.168.1.127
4	192.168.1.245/29	192.168.1.240	192.168.1.247
5	192.168.1.253/30	192.168.1.252	192.168.1.255

Answers to Practice Adding VLSM Subnets

This section lists the answers to the four practice problems in the section "Practice Adding New VLSM Subnets," earlier in this chapter. The four problems for this section used the same set of five preexisting subnets. Table 20-11 lists those subnet IDs and subnet broadcast addresses, which define the lower and higher ends of the range of numbers in each subnet.

Table 20-11. Preexisting Subnets for the Add a VLSM Subnet Problems in This Chapter



Subnet	Subnet Number	Broadcast Address
1	10.0.0.0/24	10.0.0.255
2	10.0.1.0/25	10.0.1.127
3	10.0.2.0/26	10.0.2.63
4	10.0.3.0/27	10.0.3.31

The rest of the explanations follow the five-step process outlined earlier in the section "Adding a New Subnet to an Existing VLSM Design," except that the explanations ignore Step 3 because Step 3's results in each case are already listed in Table 20-11.

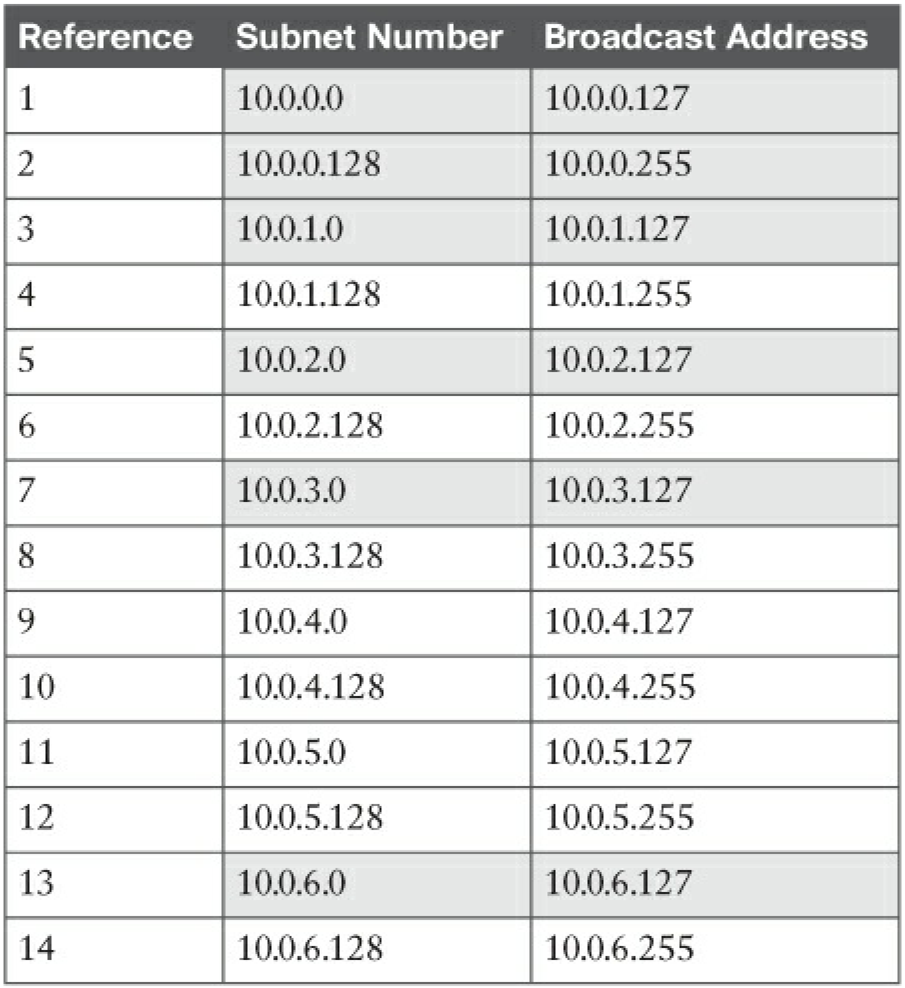
Problem 1

Step 1. The problem statement tells us to use /24.

Step 2. The subnets would be 10.0.0.0, 10.0.1.0, 10.0.2.0, 10.0.3.0, 10.0.4.0, 10.0.5.0, and so on, counting by 1 in the third octet.

Step 4. The first four new possible subnets (10.0.0.0/24, 10.0.1.0/24, 10.0.2.0/24, and 10.0.3.0/24) all overlap with the existing subnets (see Table 20-12). 10.0.6.0/24 also overlaps.

Table 20-12. First 14 Subnets of Network 10.0.0.0, Using /25 Mask



Reference	Subnet Number	Broadcast Address
1	10.0.0.0	10.0.0.127
2	10.0.0.128	10.0.0.255
3	10.0.1.0	10.0.1.127
4	10.0.1.128	10.0.1.255
5	10.0.2.0	10.0.2.127
6	10.0.2.128	10.0.2.255
7	10.0.3.0	10.0.3.127
8	10.0.3.128	10.0.3.255
9	10.0.4.0	10.0.4.127
10	10.0.4.128	10.0.4.255
11	10.0.5.0	10.0.5.127
12	10.0.5.128	10.0.5.255
13	10.0.6.0	10.0.6.127
14	10.0.6.128	10.0.6.255

Step 5. 10.0.4.0/24 is the numerically lowest new subnet number that does not overlap with the existing subnets.

Problem 2

Step 1. The problem statement tells us to use /23.

Step 2. The subnets would be 10.0.0.0, 10.0.2.0, 10.0.4.0, 10.0.6.0, 10.0.8.0, and so on, counting by 2 in the third octet.

Step 4. Three of the first four new possible subnets (10.0.0.0/23, 10.0.2.0/23, and 10.0.6.0/23) all overlap with existing subnets.

Step 5. 10.0.4.0/23 is the numerically lowest new subnet number that does not overlap with the existing subnets.

Problem 3

Step 1. The problem statement tells us to use /22.

Step 2. The subnets would be 10.0.0.0, 10.0.4.0, 10.0.8.0, 10.0.12.0, and so on, counting by 4 in the third octet.

Step 4. The first two new possible subnets (10.0.0.0/22 and 10.0.4.0/22) overlap with existing subnets.

Step 5. 10.0.8.0/22 is the numerically lowest new subnet number that does not overlap with the existing subnets.

Problem 4

The answer for this problem requires more detail than the others, because the *25 mask creates a larger number of subnets that might overlap with the preexisting subnets. For this problem, at Step 1, you already know to use mask* 25. Table 20-12 shows the results of Step 2, listing the first 14 subnets of network 10.0.0.0 when using mask /25. For Step 4, Table 20-12 also highlights the overlapped subnets in gray. To complete the task at Step 5, search the table sequentially and find the first nongrayed subnet, 10.0.1.128/25.

Chapter 21. Route Summarization

This chapter covers the following exam topics:

IP addressing (IPv4 / IPv6)

Identify the appropriate IPv4 addressing scheme using VLSM and summarization to satisfy addressing requirements in a LAN/WAN environment.

Troubleshooting

Troubleshoot and correct common problems associated with IP addressing and host configurations.

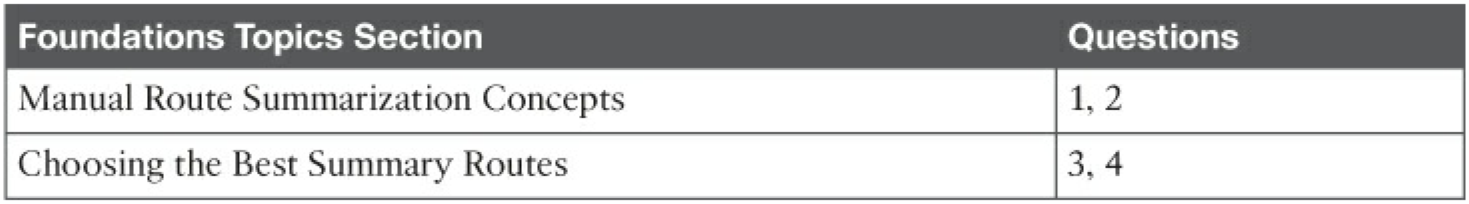
Route-summarization tools allow engineers to advertise one route that replaces several smaller routes, with the new route matching the same range of addresses. Doing so alleviates some of the waste: wasted effort, bandwidth, RAM, and CPU.

This chapter first examines manual route summarization concepts. The concepts rely on math that uses the same principles as subnetting math, and it relies on a good subnetting plan that assigns subnets in anticipation of future attempts to do route summarization. This first section of the chapter shows the math and the concepts. The second half of the chapter then shows a systematic way to find out the summary route that is the best summary route to create when configuring summary routes.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 21-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundations Topics Section	Questions
Manual Route Summarization Concepts	1, 2
Choosing the Best Summary Routes	3, 4

1. Which of the following summarized subnets is the smallest (smallest range of addresses) summary route that includes subnets 10.3.95.0, 10.3.96.0, and 10.3.97.0, mask 255.255.255.0?
   - **a.** 10.0.0.0 255.0.0.0
   - **b.** 10.3.0.0 255.255.0.0
   - **c.** 10.3.64.0 255.255.192.0
   - **d.** 10.3.64.0 255.255.224.0
2. Which of the following summarized subnets are not valid summaries that include subnets 10.1.55.0, 10.1.56.0, and 10.1.57.0, mask 255.255.255.0? (Choose two answers.)
   - **a.** 10.0.0.0 255.0.0.0
   - **b.** 10.1.0.0 255.255.0.0
   - **c.** 10.1.55.0 255.255.255.0
   - **d.** 10.1.48.0 255.255.248.0
   - **e.** 10.1.32.0 255.255.224.0
3. Which of the following would be considered the best subnet/mask to add for a new summary route that summarizes routes for subnets 10.1.12.0/24, 10.1.14.0/24, and 10.1.15.0/24?
   - **a.** 10.1.0.0/20
   - **b.** 10.1.8.0/21
   - **c.** 10.1.12.0/21
   - **d.** 10.1.12.0/22
4. Which of the following would be considered the best subnet/mask to add for a new summary route that summarizes routes for subnets 192.168.1.64/28, 192.168.1.80/28, and 192.168.1.96/28?
   - **a.** 192.168.1.0/25
   - **b.** 192.168.1.64/26
   - **c.** 192.168.1.32/26
   - **d.** 192.168.1.64/27

Answers to the "Do I Know This Already?" quiz:

1 C **2** C and D **3** D **4** B

Foundation Topics

Manual Route Summarization Concepts

Small networks might have only a few dozen routes in their routers' routing tables, but the larger the internetwork, the larger the number of routes. Some enterprises might have tens of thousands of subnets, if not more. Even with the effect of decreasing the number of routes through summarization, Internet router BGP tables have come close to the 450,000 mark as of a recent check in 2012.

As a router's routing table grows, problems can occur. The tables themselves consume memory in a router. Routing (packet forwarding) requires the router to match a route in the routing table, and searching a longer table generally takes more time and more work by the CPU. Routing protocols require more work to process the routes and more bandwidth to advertise the routes. With a large routing table, it takes more time to troubleshoot problems, because the engineers working on the network need to sift through more information.

Route summarization allows network engineers to help overcome some of these scaling problems by replacing many routes for smaller subnets with one route to what looks like a larger subnet. This first major section of the chapter walks you through the basics of how route summarization works and its impact on the routers in an IPv4 network. This section also shows how the subnetting plan needs to consider the need for route summarization ahead of time and describes how to verify route summarization by using the **show ip route** command.

Note

This chapter refers to route summarization as *manual route summarization*, in contrast to the another topic called *autosummarization*. Of the two, manual summarization is actually the tool most network engineers choose to use, while autosummarization refers to a feature of how some older routing protocols work. The term *manual* means that an engineer configures one or more commands that cause the summary route to be created. The CCNA ICND2 200-101 Official Cert Guide discusses *autosummarization*, which creates summary routes to overcome a problem with some routing protocols.

Route Summarization Basics

Imagine a small router, with limited CPU and memory, sitting in a large enterprise network. This network has over 10,000 subnets. This one small router dutifully learns all the routes with its routing protocols and adds them to its routing table. Those routes consume memory; the routing protocols take more work because of the sheer volume. Also, the long routing table means that searching the table to match a route can take longer.

Most of those 10,000 routes have the exact same forwarding instructions: to send packets out one particular interface that points toward the core of the enterprise network. Wouldn't it be great if, instead of having several thousands of those routes, this small router could have one route that matches all those same packets with instructions to forward those packets out that same interface? That's exactly what route summarization does.

Route summarization allows engineers to configure a routing protocol so that it advertises one route, replacing several smaller routes. This process creates a new summary route that matches the same range of addresses as the original routes. For example, instead of advertising routes for a lot of *24 subnets, such as 172.16.1.0*24, 172.16.2.0/24, 172.16.3.0/24, and so on, the router might simply advertise a route for 172.16.0.0/16, and not advertise all those smaller subnets.

Route summarization has many benefits. It reduces the size of routing tables, while still allowing the router to route packets to all the destinations in the network. The shorter table means that routing performance can be improved and memory can be saved inside each router. Summarization also improves convergence time for routing protocols, because the routing protocol has much less work to do.

Route Summarization and the IPv4 Subnetting Plan

For route summarization to work best, the IPv4 subnetting plan should be designed with route summarization in mind. Route summarization combines multiple routes into one route, but for that to work, the original routes must be in the same numeric range. That can happen by accident, but it works much better with planning. For example, Figure 21-1 shows a sample internetwork, with two sets of four subnets that could be summarized (some on the left, some on the right). Note that the subnetting plan placed subnets that begin with 10.2 on the left and those that begin with 10.3 on the right, which makes route summarization a little easier. To see why, focus on the right side for now, and ignore the subnets on the left. The figure shows the conditions before route summarization, for routes learned by R1, for the subnets on the right.

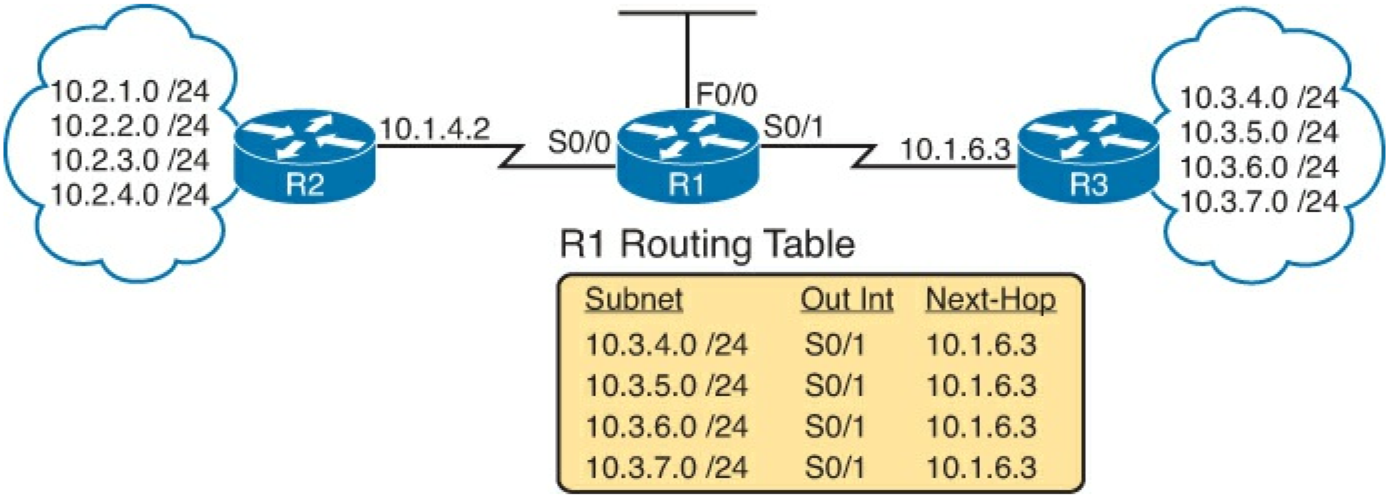

10.2.1.0 /24
10.2.2.0 /24
10.2.3.0 /24
10.2.4.0 /24
R2
10.1.4.2
S0/0
F0/0
R1
S0/1
10.1.6.3
R3
10.3.4.0 /24
10.3.5.0 /24
10.3.6.0 /24
10.3.7.0 /24
R1 Routing Table
Subnet
Out Int
Next-Hop
10.3.4.0 /24 S0/1 10.1.6.3
10.3.5.0 /24 S0/1 10.1.6.3
10.3.6.0 /24 S0/1 10.1.6.3
10.3.7.0 /24 S0/1 10.1.6.3

Figure 21-1. Small Internetwork with Good Candidates for Route Summarization

Manual route summarization causes a router to cease advertising some routes, instead advertising a route that contains a superset of all the addresses. To do so, the router that creates the summary must be configured to know the subnet number and mask to advertise in a new summary route. The routing protocol stops advertising the old smaller routes (called subordinate routes), now advertising only the summary route.

Figure 21-2 continues the example begun in Figure 21-1, showing the effect of a summary route configured on Router R3. That summary route replaces the routes for all four of the subnets on the right. Just to make the math easier, the summary route uses a subnet of 10.3.0.0/16. Note that 10.3.0.0/16 does include all the four original subnets shown in Figure 21-1 (plus other addresses).

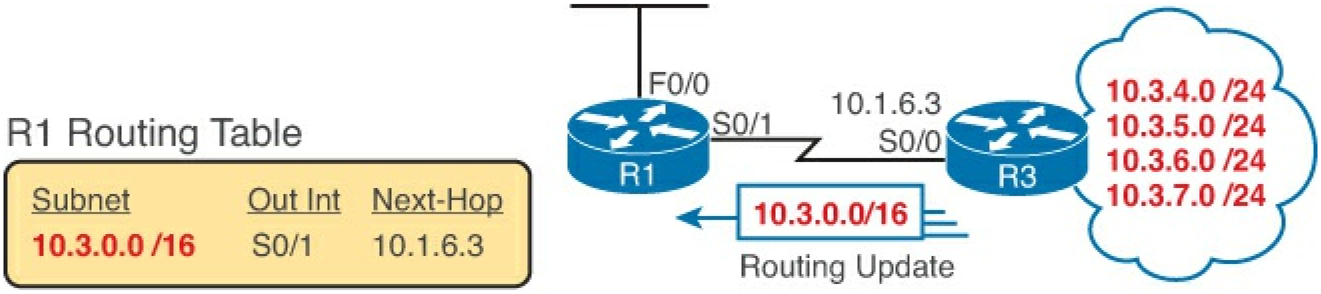

R1 Routing Table
Subnet
Out Int
Next-Hop
10.3.0.0 /16 S0/1 10.1.6.3
F0/0
R1
S0/1
10.1.6.3
S0/0
R3
10.3.0.0/16
Routing Update
10.3.4.0 /24
10.3.5.0 /24
10.3.6.0 /24
10.3.7.0 /24

Figure 21-2. Routes for the Four Subnets on the Right Summarized into One Route

By creating the summary route configuration on R3, R1 (and other routers farther into the network) receive the benefit. R1's routing table decreases in size. More importantly, R1 can still forward packets to those same original four subnets, out the same S0/1 interface, to the same next-hop router (10.1.6.3, which is R3).

Verifying Manually Summarized Routes

Route summarization impacts the routing tables on the routers, with different results depending on whether a router simply learned the summary or whether the router created the summary. Example 21-1 shows R1's routing table, both before the summary route was configured on R3 (as shown in Figure 21-1) and then after R3 added the summary route configuration (as shown in Figure 21-2). (Note that the example shows only the routes learned by the routing protocol, rather than including the connected routes.)

Example 21-1. R1 Routing Table: Before and After Summary Route Was Learned

Click here to view code image

```
! First, the before case
R1# show ip route rip
! (Legend lines omitted for brevity)
10.0.0.0/8 is variably subnetted, 14 subnets, 3 masks
R 10.2.1.0/24 [120/1] via 10.1.4.2, 00:00:20, Serial0/0
R 10.2.2.0/24 [120/1] via 10.1.4.2, 00:00:20, Serial0/0
R 10.2.3.0/24 [120/1] via 10.1.4.2, 00:00:20, Serial0/0
R 10.2.4.0/24 [120/1] via 10.1.4.2, 00:00:20, Serial0/0
R 10.3.4.0/24 [120/1] via 10.1.6.3, 00:00:12, Serial0/1
R 10.3.5.0/24 [120/2] via 10.1.6.3, 00:00:12, Serial0/1
R 10.3.6.0/24 [120/3] via 10.1.6.3, 00:00:12, Serial0/1
R 10.3.7.0/24 [120/4] via 10.1.6.3, 00:00:12, Serial0/1


! Now, the after case.
```

```
R1# show ip route
! (Legend lines omitted for brevity)

10.0.0.0/8 is variably subnetted, 11 subnets, 4 masks
R 10.2.1.0/24 [120/1] via 10.1.4.2, 00:00:20, Serial0/0
R 10.2.2.0/24 [120/1] via 10.1.4.2, 00:00:20, Serial0/0
R 10.2.3.0/24 [120/1] via 10.1.4.2, 00:00:20, Serial0/0
R 10.2.4.0/24 [120/1] via 10.1.4.2, 00:00:20, Serial0/0
R 10.3.0.0/16 [120/1] via 10.1.6.3, 00:00:04, Serial0/1
```

First, look at the top half of the output, which shows the before case (based on Figure 21-1). The **show ip route rip** command lists only the RIP-learned routes, lists statistics that state R1 knows 14 subnets, and then lists eight routes learned with Routing Information Protocol (RIP). The other six routes are R1's three connected routes and three local routes for its three interfaces. In particular, note the four RIP-learned routes for subnets that begin with 10.3.

Next, look at the after case in the second part of the example. The big difference, of course, is that the before case shows the four individual subnets that begin with 10.3, and the latter case shows only the summary route for 10.3.0.0/16 instead. That summary route looks like any other route, with a subnet, mask, next-hop router (10.1.6.3), and outgoing interface (Serial 0/1). As it turns out, nothing in the line tells you that the route is a summary route as opposed to a subnet that exists somewhere in the internetwork.

Neither this book nor the ICND2 book discusses how to configure summary routes. Instead, the focus of route summarization here is to understand the big ideas, see the benefits, and be ready to work with routes that happen to be summary routes. To that end, the second half of this chapter looks at some math related to summary routes that shows how to choose the best subnet and mask to use in a summary route.

Choosing the Best Summary Routes

Manual route summarization works best when the subnetting plan considered summarization in the first place. For example, the earlier examples with Figures 21-1 and 21-2 used a well-thought-out plan, with the engineers only using subnets beginning with 10.2 for subnets off R2 and subnets that begin with 10.3 for subnets off R3.

When creating a summary route, some network engineer types a subnet and mask in a configuration command. Many combinations of subnet/mask can work for a given need; however, not all those options are the best option. The word *best*, when applied to choosing what summary route to configure, means that the summary should include all the subordinate subnets, but *with as few other addresses as is possible*. For the purposes of this book, the best summary route can be defined as follows:

Key Topic

> The summary route with the smallest range of addresses that includes all the addresses in all the subnets you want to summarize with that one summary route.

For example, in the earlier summarization example, subnets 10.3.4.0/24, 10.3.5.0/24, 10.3.6.0/24, and 10.3.7.0/24 together define a range of addresses from 10.3.4.0 to 10.3.7.255. The summary route in Example 21-1 (10.3.0.0/16) works. However, it includes a lot of IP addresses that are not in those four original subnets, because it includes the range from 10.3.0.0 to 10.3.255.255. As it turns out, a different option for this summary route—10.3.4.0/22—has a range of addresses that exactly matches the range for these four subnets (10.3.4.0–10.3.7.255). By the definition listed here, both 10.3.0.0/16 and 10.3.4.0/22 work, but 10.3.40/22 is the best summary route.

This second major section of the chapter shows how to take a set of existing routes and find the best summary route.

The Process to Find the Best Summary Route

To find the best summary route, you can use trial and error, use educated guesses, use a subnet calculator, or use any other method you like. For the purposes of CCENT and CCNA, using a simpler decimal-based process to find the best summary route probably makes the most sense. The process uses familiar skills: taking a subnet ID/mask and finding the subnet broadcast address, as discussed back in Chapter 14, "Analyzing Existing Subnets." If you can do that math with confidence, this process should be no problem. (If not, consider going back to review subnetting math from Chapter 14 before finishing this chapter.)

Key Topic

Here are the steps for finding the best summary route, using decimal math, with some examples to follow:

Step 1. List all to-be-summarized (subordinate) subnet numbers in decimal, in order, from lowest to highest, along with their matching subnet broadcast addresses.

Step 2. Note the low and high end of the range of addresses for all combined subnets by noting the numerically lowest subnet ID and numerically highest subnet broadcast address.

Step 3. Pick a starting point prefix length /P for Step 4, as follows: Pick the shortest prefix length mask of all the subordinate subnets, and then subtract 1.

Step 4. Calculate a new potential summary subnet/mask, with matching broadcast address, based on the lowest subordinate subnet ID from the original list and the current prefix length.

  A. If the calculated range of addresses includes the entire range from Step 2, you have found the best summary route.

  B. If not, subtract 1 from the prefix length used in the most recent calculation and repeat Step 4.

As usual, the steps themselves can be daunting. Here's the shorter version: Pick the lowest subnet ID from the list, keep shortening the shortest prefix-style mask, calculate a new subnet ID based on those details, and see whether the new subnet includes all the addresses in the list of original subnets. But the best way to really understand is to see a few examples and then do a few.

Sample "Best" Summary on Router R3

R3, in earlier Figures 21-1 and 21-2, connects to subnets 10.3.4.0/24, 10.3.5.0/24, 10.3.6.0/24, and 10.3.7.0/24. Figure 21-3 shows the results of the first three steps of the process, applied to the three routes off Router R3. Following the steps:

Step 1. Relist the subnet IDs (and prefix lengths) and calculate the subnet broadcast addresses.

Step 2. Identify 10.3.4.0 as the lowest subnet ID and 10.3.7.255 as the highest subnet broadcast address, defining the low and high end of the range that the summary must include.

Step 3. With all four masks as *24, subtract 1 from 24, so the initial value of* P to try is /23.

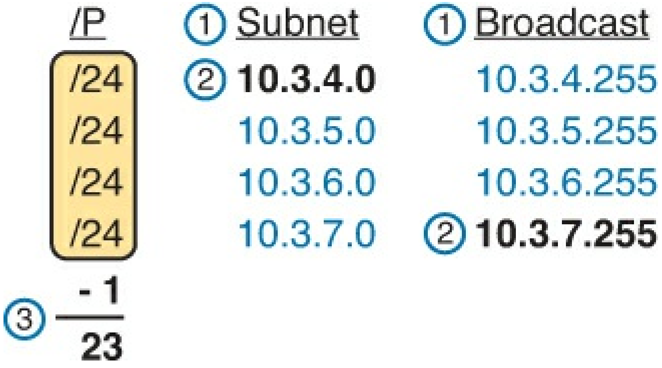


Figure 21-3. Finding the Best Summary, First Three Steps, First Example

Step 4 of the process requires some math that gets repeated until the best summary has been found. For the first time through the math at Step 4, use the /P calculated at Step 3 (in this case, /23). Then, each time Step 4's math does not result in confirming that you found the best summary route, repeat the math with a shorter prefix length mask, until the best summary is found.

This initial pass through Step 4 in this case uses subnet ID 10.3.4.0 and mask /23. At this point, you do not even know whether 10.3.4.0 would be a subnet number when using mask /23, so do the math as if you were trying to calculate both the subnet number and broadcast address. The calculation shows

  /23: subnet 10.3.4.0, broadcast 10.3.5.255

At Step 4A, you compare the newly calculated subnet address range with the range of addresses in the original subnets, as identified in Step 2. The new potential best summary route doesn't include the entire range of addresses for the original subnets. So, at Step 4B, subtract 1 from the prefix length (23 – 1 = 22) and start Step 4 again, with a /22 mask.

At the next pass through Step 4, again starting with the lowest original subnet ID (10.3.4.0), using the current prefix /22, calculating the subnet ID and broadcast, you get

  /22: subnet 10.3.4.0, broadcast 10.3.7.255

Back to Step 4A, this range exactly matches the range shown in Figure 21-3, so you have found the subnet and mask to use in the best summary route: 10.3.4.0/22.

Sample "Best" Summary on Router R2

Figure 21-1 shows four subnets on the right as well as four subnets on the left. So far, this chapter has mostly ignored the subnets on the left, but now you can calculate the best summary route for those subnets. Those routes are for subnets 10.2.1.0/24, 10.2.2.0/24, 10.2.3.0/24, and 10.2.4.0/24.

Figure 21-4 shows the results of the first three steps.

Step 1. Relist the subnet IDs (and prefix lengths) and calculate the subnet broadcast addresses.

Step 2. Identify 10.2.1.0 as the lowest subnet ID and 10.2.4.255 as the highest subnet broadcast address, defining the low and high end of the range that the summary must include.

Step 3. As with the previous example, with all four masks as *24, you choose an initial* P to use of 1 less, or /23.

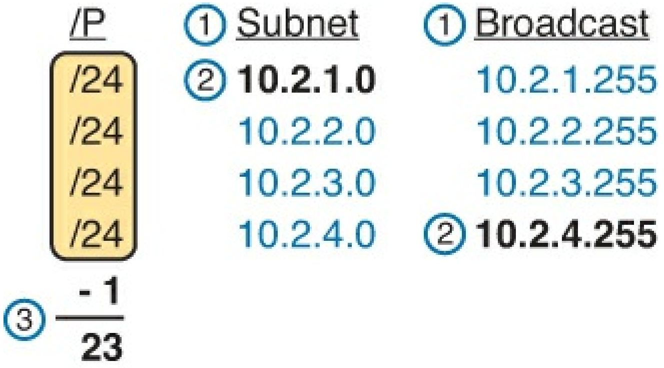


Figure 21-4. Finding the Best Summary, First Three Steps, Second Example

This initial pass through Step 4 uses subnet ID 10.2.1.0 and mask /23. At this point, you do not even know whether 10.2.1.0 would be a subnet number when using mask /23, so do the math as if you were trying to calculate both the subnet number and broadcast address. In this case, the calculation would show

/23: subnet 10.2.0.0, broadcast 10.2.1.255

At Step 4A, comparing this range to the range shown in Figure 21-4, this new potential best summary route doesn't include the entire range. So, at Step 4B, subtract 1 from the prefix length (23 – 1 = 22) and start Step 4 again, with a /22 mask.

Taking the next pass through Step 4, starting with the lowest original subnet ID (10.2.1.0) and the current prefix /22, calculating the subnet ID and broadcast, you get

/22: subnet 10.2.0.0, broadcast 10.2.3.255

This new range includes the addresses from three of the four original subordinate subnets, but not from subnet 10.2.4.0/24. So, one more pass through Step 4 is required, this time with mask /21, which gives you

/21: subnet 10.2.0.0, broadcast 10.2.7.255

This new subnet includes the entire range, so this is the best summary route for those subnets.

Practice Choosing the Best Summary Routes

Table 21-2 lists four sets of subnets that need to be summarized as part of a summary route. Find the subnet number/mask combination that is the best summary route, at least by definition in the previous section.

Table 21-2. Practice Problems: Finding the Best Summary Route

Problem 1	Problem 2	Problem 3	Problem 4
10.1.50.0/23	172.16.112.0/24	192.168.1.160/28	172.16.125.0/24
10.1.48.0/23	172.16.114.0/25	192.168.1.152/30	172.16.126.0/24
10.1.46.0/23	172.16.116.0/23	192.168.1.192/29	172.16.127.0/24
10.1.52.0/23	172.16.111.0/24	192.168.1.128/28	172.16.128.0/24

The answers are shown in the section "Answers to Earlier Practice Problems," later in this chapter.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 21-3 lists these key topics and where each is discussed.

Table 21-3. Key Topics for Chapter 21

Key Topic Element	Description	Page Number
Definition	Criteria for what makes a summary route the best summary route for a given set of subnets	582
List	Process for finding the best manual summary route	583

Appendix I Practice Problems

DVD Appendix I, "Practice for Chapter 21: Route Summarization," lists additional practice problems and answers.

Definition of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

classful routing protocol
classless routing protocol
overlapping subnets
variable-length subnet masks (VLSM)
contiguous network
discontiguous network
summary route

Answers to Earlier Practice Problems

This section lists the answers to the practice problems listed in the earlier section "Practice Choosing the Best Summary Routes." This section shows the answers, along with a description of how to use the process in this book to solve the problems.

For each problem, the first table lists the results of the first two steps; the gray boxes show the low and high end of the range that the new summary route must enclose. The second table for each problem shows the results of each pass through Step 4, with the final (rightmost) pass showing the correct answer.

Problem 1

Table 21-4. Practice Problem 1: First Two Steps

Subnet IDs/Masks	Subnet Broadcasts
10.1.50.0/23	10.1.51.255
10.1.48.0/23	10.1.49.255
10.1.46.0/23	10.1.47.255
10.1.52.0/23	10.1.53.255

For Problem 1, at Step 3, all masks are *23, so the initial mask will be one smaller, or* 22. Finding the correct answer requires four passes through calculating a new subnet ID and mask, with the final answer shown in Table 21-5.

Table 21-5. Practice Problem 1: Multiple Passes Through Step 4 (Correct Answers Highlighted)

All Passes Use 10.1.46.0	1st Pass: /22	2nd Pass: /21	3rd Pass: /20	4th Pass: /19
Subnet ID	10.1.44.0	10.1.40.0	10.1.32.0	10.1.32.0
Broadcast Address	10.1.47.255	10.1.47.255	10.1.47.255	10.1.63.255

Problem 2

Table 21-6. Practice Problem 2: First Two Steps

Subnet IDs/Masks	Subnet Broadcasts
172.16.112.0/24	172.16.112.255
172.16.114.0/25	172.16.114.127
172.16.116.0/23	172.16.117.255
172.16.111.0/24	172.16.111.255

For Problem 2, at Step 3, the shortest mask is *23, so the initial mask will be 1 smaller, or* 22. Finding the correct answer requires four passes through calculating a new subnet ID and mask, with the final answer shown in Table 21-7.

Table 21-7. Practice Problem 2: Multiple Passes Through Step 4 (Correct Answers Highlighted)

All Passes Use 172.16.111.0	1st Pass: /22	2nd Pass: /21	3rd Pass: /20	4th Pass: /19
Subnet ID	172.16.108.0	172.16.104.0	172.16.96.0	172.16.96.0
Broadcast Address	172.16.111.255	172.16.111.255	172.16.111.255	172.16.127.255

Problem 3

Table 21-8. Practice Problem 3: First Two Steps

Subnet IDs/Masks	Subnet Broadcasts
192.168.1.160/28	192.168.1.175
192.168.1.152/30	192.168.1.155
192.168.1.192/29	192.168.1.199
192.168.1.128/28	192.168.1.143

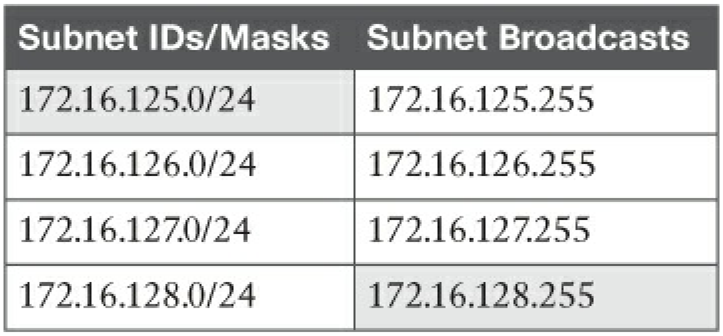
For Problem 3, at Step 3, the shortest mask is *28, so the initial mask will be 1 smaller, or* 27. Finding the correct answer requires three passes through calculating a new subnet ID and mask, with the final answer shown in Table 21-9.

Table 21-9. Practice Problem 3: Multiple Passes Through Step 4 (Correct Answers Highlighted)

All Passes Use 192.168.1.128	1st Pass: /27	2nd Pass: /26	3rd Pass: /25
Subnet ID	192.168.1.128	192.168.1.128	192.168.1.128
Broadcast Address	192.168.1.159	192.168.1.191	192.168.1.255

Problem 4

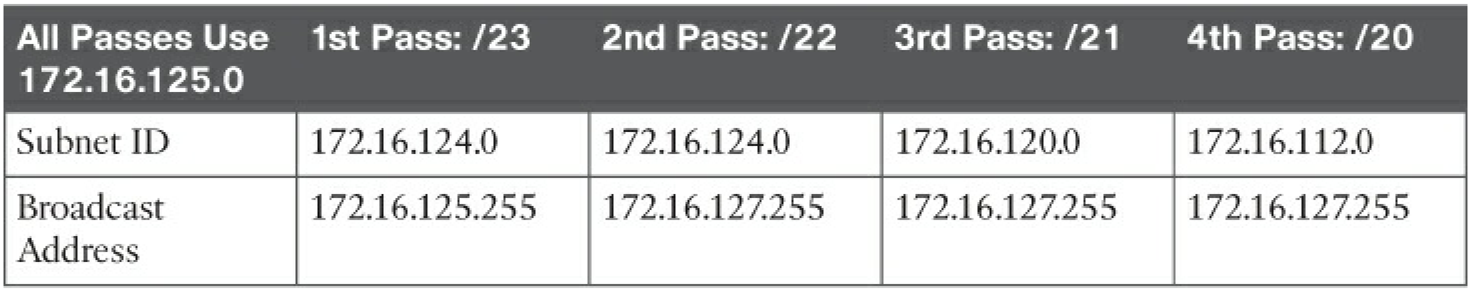
Table 21-10. Practice Problem 4: First Two Steps



Subnet IDs/Masks	Subnet Broadcasts
172.16.125.0/24	172.16.125.255
172.16.126.0/24	172.16.126.255
172.16.127.0/24	172.16.127.255
172.16.128.0/24	172.16.128.255

For Problem 4, at Step 3, the shortest mask is *24, so the initial mask will be 1 smaller, or* 23.

Table 21-11. Practice Problem 4: Multiple Passes Through Step 4



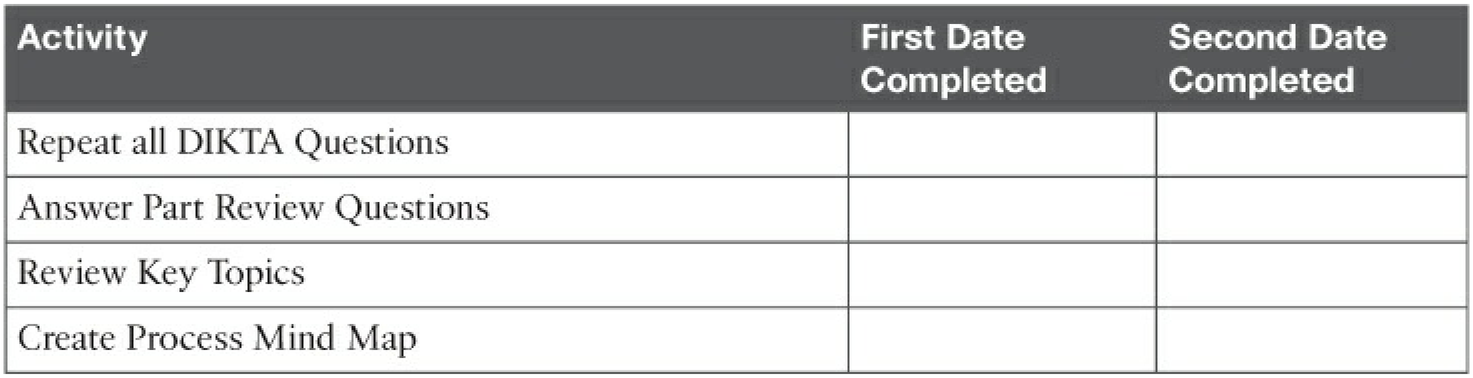
All Passes Use 172.16.125.0	1st Pass: /23	2nd Pass: /22	3rd Pass: /21	4th Pass: /20
Subnet ID	172.16.124.0	172.16.124.0	172.16.120.0	172.16.112.0
Broadcast Address	172.16.125.255	172.16.127.255	172.16.127.255	172.16.127.255

Table 21-11 still does not show the correct answer. If you keep going, it will take you all the way to *16 before you find the best summary: 172.16.0.0*16.

Part V Review

Keep track of your part review progress with the checklist in Table P5-1. Details on each task follow the table.

Table P5-1. Part V Part Review Checklist



Activity	First Date Completed	Second Date Completed
Repeat all DIKTA Questions		
Answer Part Review Questions		
Review Key Topics		
Create Process Mind Map		

Repeat All DIKTA Questions

For this task, answer the "Do I Know This Already?" questions again for the chapters in this part of the book, using the PCPT software. Refer to the Introduction to this book, heading "How to View Only DIKTA Questions by Part," for help with how to make the PCPT software show you DIKTA questions for this part only.

Answer Part Review Questions

For this task, answer the Part Review questions for this part of the book, using the PCPT software. Refer to the Introduction to this book, heading "How to View Only Part Review Questions by Part," for help with how to make the PCPT software show you Part Review questions for this part only.

Review Key Topics

Key Topic

Browse back through the chapters, and look for the Key Topic icons. If you do not remember some details, take the time to reread those topics.

Create Process Mind Map

This book part explains several types of problems that can be solved by following a process outlined in the chapter. The next mind map exercise helps to review the big ideas of what each type of problem does. This review does not focus on the details of how to find the answer to any one problem, leaving that for all the other practice suggestions included near the end of Chapters 19, 20, and 21.

Those chapters discussed the following types of problems that can be solved with some arithmetic:

- **Choosing Subnet Masks:** Based on design requirements, choose one mask to use throughout a classful IP network.
- **Finding All Subnet IDs:** Calculate all subnet IDs of a network.
- **Finding VLSM Overlaps:** Discovering mistakes in a design in which two or more subnets' address ranges overlap.
- **Adding New Subnets to an Existing VLSM Design:** Discovering an open slot in the existing subnet design into which a new VLSM subnet can be added.
- **Finding the Best Summary Route:** Based on a list of subnets/masks, find the summary route that would summarize those routes but with the least number of extra addresses within the summary.

Create a mind map with a branch for each topic in the list. For each branch, begin with the core concept and branch into three subtopics, as shown in this list and in Figure P5-1:

- **Given:** The information you have and the assumptions you make to start the problem.
- **Process:** The information or terms used during the process. Do not write the specific steps of the process; the goal here is just to make memory connections so that you know it is this process, and not some other process.
- **Result:** The facts you determine by doing the problem.

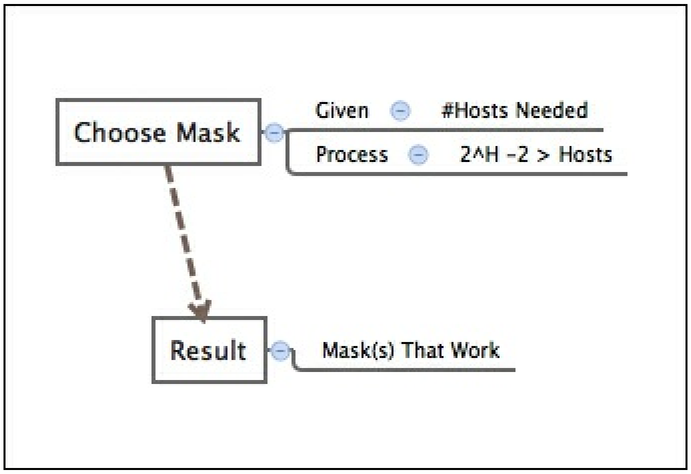
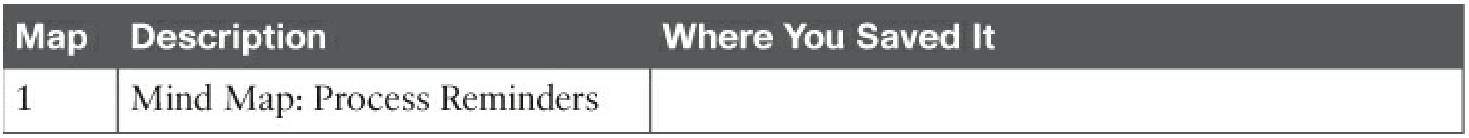

Choose Mask
Given
#Hosts Needed
Process
2^H -2 > Hosts
Result
Mask(s) That Work

Figure P5-1. Sample Mind Map for Part V Mind Map

> **Note**
>
> For more information on mind mapping, refer to the Introduction, in the section "About Mind Maps."

If you do choose to use mind map software, rather than paper, you might want to remember where you stored your mind map files. Table P5-2 lists the mind maps for this part review and a place to record those filenames.

Table P5-2. Configuration Mind Maps for Part V Review



Map	Description	Where You Saved It
1	Mind Map: Process Reminders	

Appendix O, "Mind Map Solutions," lists a sample mind map answer, but as usual, your mind map can and will look different.

Part VI: IPv4 Services

So far, this book has shown the basics for building IPv4 networks using routers, switches, Ethernet LANs, and serial links. Part VI completes this book's topics on IPv4 networks by looking at a couple of services that help secure enterprise networks as well as create useful addressing options when connecting to the Internet.

Chapters 22 and 23 discuss the basics and more advanced features of IPv4 access control lists (ACL). ACLs are IPv4 packet filters that can be programmed to look at IPv4 packet headers, make choices, and either allow a packet through or discard the packet. Along the way, Chapter 23 also discusses some other network security topics in addition to ACLs. Chapter 24, the last chapter in this part, discusses Network Address Translation (NAT). NAT helps solve a big problem with IPv4 addressing in the Internet, and is used by almost every enterprise and home user of the Internet.

Chapter 22: Basic IPv4 Access Control Lists

Chapter 23: Advanced IPv4 ACLs and Device Security

Chapter 24: Network Address Translation

Part VI Review

Chapter 22. Basic IPv4 Access Control Lists

This chapter covers the following exam topics:

- **IP Services**
  - Describe the types, features, and applications of ACLs
    - Standard
    - Numbered
    - Log option
  - Configure and verify ACLs in a network environment
    - Numbered
    - Log option
- **Network Device Security**
  - Configure and verify ACLs to filter network traffic
- **Troubleshooting**
  - Troubleshoot and Resolve ACL issues
    - Statistics
    - Permitted networks
    - Direction
    - Interface

Most every other topic in the scope of CCENT focuses on achieving a core goal of any TCP/IP network: delivering IPv4 packets from the source host to the destination host. This chapter, along with the next chapter, focuses instead on preventing a subset of those packets from being allowed to reach their destinations, by using IPv4 access control lists (ACL).

IPv4 ACLs have many uses, but the CCENT exam focuses on their most commonly known use: as packet filters. You want hosts in one subnet to be able to communicate throughout your corporate network, but maybe there is a pocket of servers with sensitive data that must be protected. Maybe government privacy rules require you to further secure and protect access, not just with usernames and login, but even to protect the ability to deliver a packet to the protected host or server. IP ACLs provide a useful solution to achieve those goals.

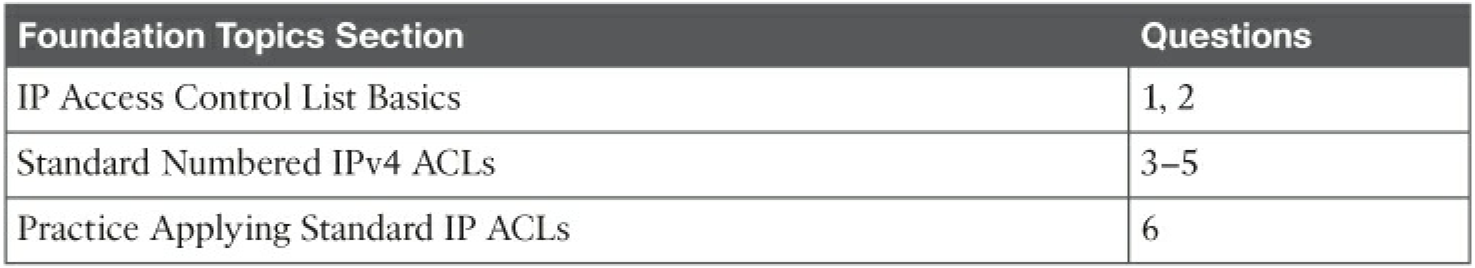
This chapter discusses the basics of IPv4 ACLs, and in particular, one type of IP ACL: standard numbered IP ACLs. Chapter 23, "Advanced IPv4 ACLs and Device Security," completes the discussion by describing other types of IP ACLs.

> **Note**
>
> While IPv6 ACLs exist as well, they are not included in this book or the *Cisco CCNA Routing and Switching ICND2 200-101 Official Cert Guide*. All other references to IP ACLs in this chapter refer specifically to IPv4 ACLs.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 22-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
IP Access Control List Basics	1, 2
Standard Numbered IPv4 ACLs	3–5
Practice Applying Standard IP ACLs	6

1. Barney is a host with IP address 10.1.1.1 in subnet 10.1.1.0/24. Which of the following are things that a standard IP ACL could be configured to do? (Choose two answers.)
   a. Match the exact source IP address.
   b. Match IP addresses 10.1.1.1 through 10.1.1.4 with one **access-list** command without matching other IP addresses.
   c. Match all IP addresses in Barney's subnet with one **access-list** command without matching other IP addresses.
   d. Match only the packet's destination IP address.
2. Which of the following answers list a valid number that can be used with standard numbered IP ACLs? (Choose two

answers.)

- **a.** 1987
- **b.** 2187
- **c.** 187
- **d.** 87

3. Which of the following wildcard masks is most useful for matching all IP packets in subnet 10.1.128.0, mask 255.255.255.0?
   - **a.** 0.0.0.0
   - **b.** 0.0.0.31
   - **c.** 0.0.0.240
   - **d.** 0.0.0.255
   - **e.** 0.0.15.0
   - **f.** 0.0.248.255
4. Which of the following wildcard masks is most useful for matching all IP packets in subnet 10.1.128.0, mask 255.255.240.0?
   - **a.** 0.0.0.0
   - **b.** 0.0.0.31
   - **c.** 0.0.0.240
   - **d.** 0.0.0.255
   - **e.** 0.0.15.255
   - **f.** 0.0.248.255
5. ACL 1 has three statements, in the following order, with address and wildcard mask values as follows: 1.0.0.0 0.255.255.255, 1.1.0.0 0.0.255.255, and 1.1.1.0 0.0.0.255. If a router tried to match a packet sourced from IP address 1.1.1.1 using this ACL, which ACL statement does a router consider the packet to have matched?
   - **a.** First
   - **b.** Second
   - **c.** Third
   - **d.** Implied deny at the end of the ACL
6. Which of the following **access-list** commands matches all packets sent from hosts in subnet 172.16.5.0/25?
   - **a. access-list 1 permi**t **172.16.0.5 0.0.255.0**
   - **b. access-list 1 permi**t **172.16.4.0 0.0.1.255**
   - **c. access-list 1 permi**t **172.16.5.0**
   - **d. access-list 1 permi**t **172.16.5.0 0.0.0.128**

Answers to the "Do I Know This Already?" quiz:

1 A and C **2** A and D **3** D **4** E **5** A **6** B

Foundation Topics

IPv4 Access Control List Basics

IPv4 access control lists (IP ACL) give network engineers a way to identify different types of packets. To do so, the ACL configuration lists values that the router can see in the IP, TCP, UDP, and other headers. For example, an ACL can match packets whose source IP address is 1.1.1.1, or packets whose destination IP address is some address in subnet 10.1.1.0/24, or packets with a destination port of TCP port 23 (Telnet).

IPv4 ACLs perform many functions in Cisco routers, with the most common use as a packet filter. Engineers can enable ACLs on a router so that the ACL sits in the forwarding path of packets as they pass through the router. After it is enabled, the router considers whether each IP packet will either be discarded or allowed to continue as if the ACL did not exist.

However, ACLs can be used for many other IOS features as well. As an example, ACLs can be used to match packets for applying quality of service (QoS) features. QoS allows a router to give some packets better service, and other packets worse service. For example, packets that hold digitized voice need to have very low delay, so ACLs can match voice packets, with QoS logic in turn forwarding voice packets more quickly than data packets.

This first section introduces IP ACLs as used for packet filtering, focusing on these aspects of ACLs: the locations and direction in which to enable ACLs, matching packets by examining headers, and taking action after a packet has been matched.

ACL Location and Direction

Cisco routers can apply ACL logic to packets at the point at which the IP packets enter an interface, or the point at which they exit an interface. In other words, the ACL becomes associated with an interface and for a direction of packet flow (either in or out). That is, the ACL can be applied inbound to the router, before the router makes its forwarding (routing) decision, or outbound, after the router makes its forwarding decision and has determined the exit interface to use.

The arrows in Figure 22-1 show the locations at which you could filter packets flowing left to right in the topology. For example, imagine that you wanted to allow packets sent by host A to server S1, but to discard packets sent by host B to server S1. Each arrowed line represents a location and direction at which a router could apply an ACL, filtering the packets sent by host B.

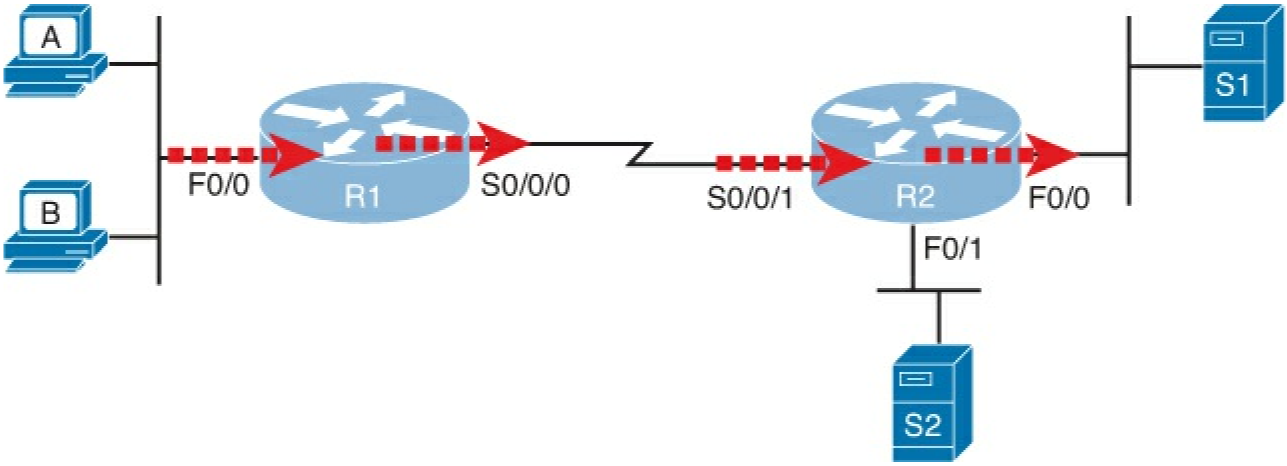


Figure 22-1. Locations to Filter Packets from Hosts A and B Going Toward Server S1

The four arrowed lines in the figure point out the location and direction for the router interfaces used to forward the packet from host B to server S1. In this particular example, those interfaces and direction are inbound on R1's F0/0 interface, outbound on R1's S0/0/0 interface, inbound on R2's S0/0/1 interface, and outbound on R2's F0/0 interface. If, for example, you enabled on ACL on R2's F0/1 interface, in either direction, that ACL could not possibly filter the packet sent from host B to server S1, because R2's F0/1 interface is not part of the route from B to S1.

Key Topic

In short, to filter a packet, you must enable an ACL on an interface that processes the packet, in the same direction the packet flows through that interface.

When enabled, the router then processes every inbound or outbound IP packet using that ACL. For example, if enabled on R1 for packets inbound on interface F0/0, R1 would compare every inbound IP packet on F0/0 to the ACL to decide that packet's fate: to continue unchanged, or to be discarded.

Matching Packets

When you think about the location and direction for an ACL, you must already be thinking about what packets you plan to filter (discard), and which ones you want to allow through. To tell the router those same ideas, you must configure the router with an IP ACL that matches packets. *Matching packets* refers to how to configure the ACL commands to look at each packet, listing how to identify which packets should be discarded, and which should be allowed through.

Each IP ACL consists of one or more configuration commands, with each command listing details about values to look for inside a packet's headers. Generally, an ACL command uses logic like "look for these values in the packet header, and if found, discard the packet." (The action could instead be to allow the packet, rather than discard.) Specifically, the ACL looks for header fields you should already know well, including the source and destination IP addresses, plus TCP and UDP port numbers.

For example, consider an example with Figure 22-2, in which you want to allow packets from host A to server S1, but to discard packets from host B going to that same server. The hosts all now have IP addresses, and the figure shows pseudocode for an ACL on R2. Figure 22-2 also shows the chosen location to enable the ACL: inbound on R2's S0/0/1 interface.

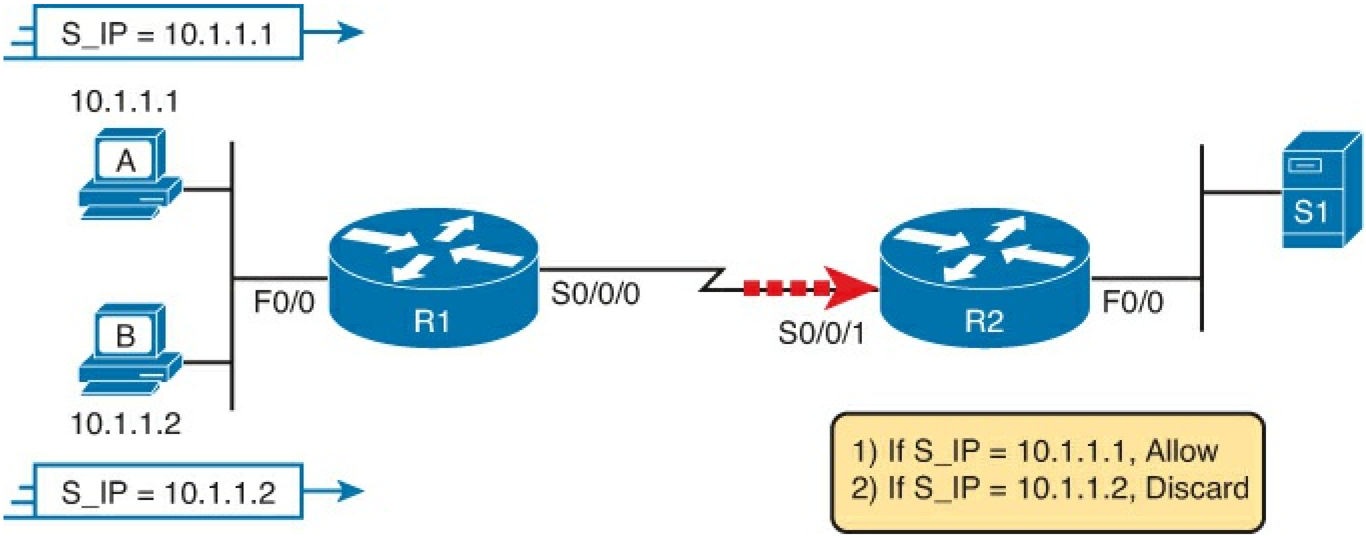


Figure 22-2. Pseudocode to Demonstrate ACL Command-Matching Logic

Figure 22-2 shows a two-line ACL in a rectangle at the bottom, with simple matching logic: both statements just look to match the source IP address in the packet. When enabled, R2 looks at every inbound IP packet on that interface and compares each packet to those two ACL commands. Packets sent by host A (source IP address 10.1.1.1) are allowed through, and those sourced by host B (source IP address 10.1.1.2) are discarded.

Taking Action When a Match Occurs

When using IP ACLs to filter packets, only one of two actions can be chosen. The configuration commands use keywords **deny** and **permit**, and they mean (respectively) to discard the packet or to allow it to keep going as if the ACL did not exist.

This book focuses on using ACLs to filter packets, but IOS uses ACLs for many more features. Those features typically use the same matching logic. However, in other cases, the **deny** or **permit** keywords imply some other action. For example, Chapter 24, "Network Address Translation," uses ACLs to match packets, but matching with a **permit** keyword tells the router to apply NAT functions that translate the IP addresses.

Types of IP ACLs

Cisco IOS has supported IP ACLs since the early days of Cisco routers. Beginning with the original standard numbered IP ACLs in the early days of IOS, which could enable the logic shown earlier around Figure 22-2, Cisco has added many ACL features, including:

- Standard Numbered ACLs (1–99)
- Extended Numbered ACLs (100–199)
- Additional ACL Numbers (1300–1999 standard, 2000–2699 extended)
- Named ACLs
- Improved Editing with Sequence Numbers

This chapter focuses solely on standard numbered IP ACLs, and Chapter 23 discusses the other three primary categories of IP ACLs. Briefly, IP ACLs will be either numbered or named in that the configuration identifies the ACL either using a number or a name. ACLs will also be either standard or extended, with extended ACLs having much more robust abilities in matching packets. Figure 22-3 summarizes the big ideas related to categories of IP ACLs.

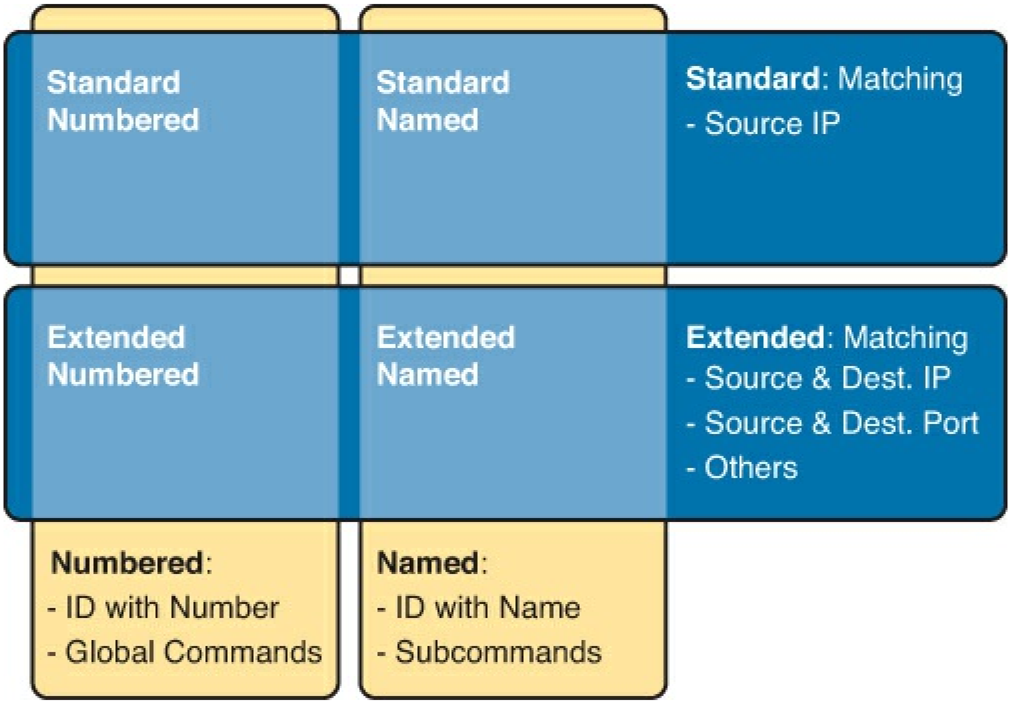

Standard Numbered
Standard Named
Standard: Matching
- Source IP
Extended Numbered
Extended Named
Extended: Matching
- Source & Dest. IP
- Source & Dest. Port
- Others
Numbered:
- ID with Number
- Global Commands
Named:
- ID with Name
- Subcommands

Figure 22-3. Comparisons of IP ACL Types

Standard Numbered IPv4 ACLs

The title of this section serves as a great introduction, if you can decode what Cisco means by each specific word. This section is about a type of Cisco filter (ACL) that matches only the source IP address of the packet (*standard*), is configured to identify the ACL using numbers rather than names (*numbered*), and it looks at IPv4 packets.

This section examines the particulars of standard numbered IP ACLs. First, it examines the idea that one ACL is a list, and what logic that list uses. Following that, the text closely looks at how to match the source IP address field in the packet header, including the syntax of the commands. This section ends with a complete look at the configuration and verification commands to implement standard ACLs.

List Logic with IP ACLs

A single ACL is both a single entity and, at the same time, a list of one or more configuration commands. As a single entity, the configuration enables the entire ACL on an interface, in a specific direction, as shown earlier around Figure 22-1. As a list of commands, each command has different matching logic that the router must apply to each packet when filtering using that ACL.

When doing ACL processing, the router processes the packet, compared to the ACL, as follows:

Key Topic

> ACLs use first-match logic. Once a packet matches one line in the ACL, the router takes the action listed in that line of the ACL, and stops looking further in the ACL.

To see exactly what that means, consider the example built around Figure 22-4. The figure shows an example ACL 1 with three lines of pseudocode. This example applies ACL 1 on R2's S0/0/1 interface, inbound (the same location as in earlier Figure 22-2).

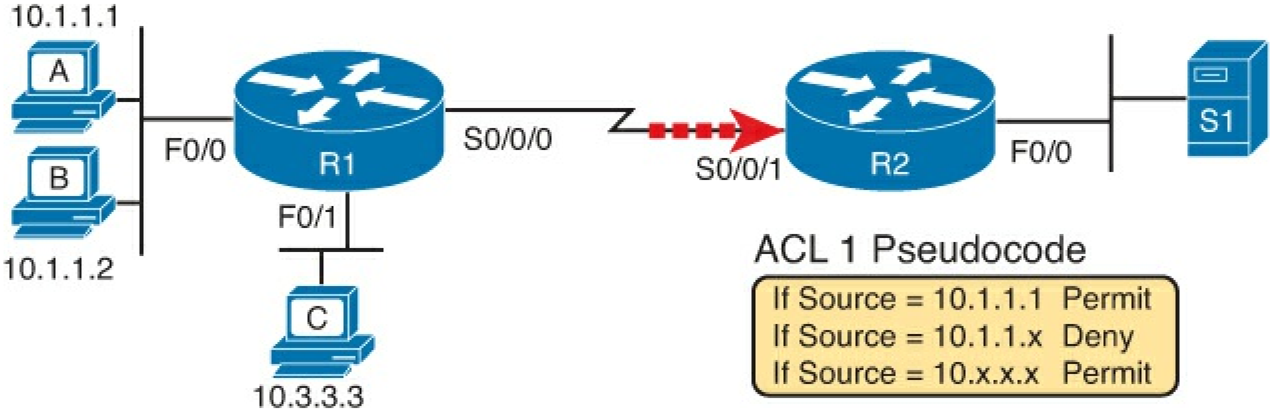

10.1.1.1
A
B
10.1.1.2
F0/0
R1
F0/1
C
10.3.3.3
S0/0/0
S0/0/1
R2
F0/0
S1
ACL 1 Pseudocode
If Source = 10.1.1.1 Permit
If Source = 10.1.1.x Deny
If Source = 10.x.x.x Permit

Figure 22-4. Backdrop for Discussion of List Process with IP ACLs

Consider the first-match ACL logic for a packet sent by host A to server S1. The source IP address will be 10.1.1.1, and it will be routed so that it enters R2's S0/0/1 interface, driving R2's ACL 1 logic. R2 compares this packet to the ACL, matching the first item in the list with a permit action. So this packet should be allowed through, as shown in Figure 22-5, on the left.

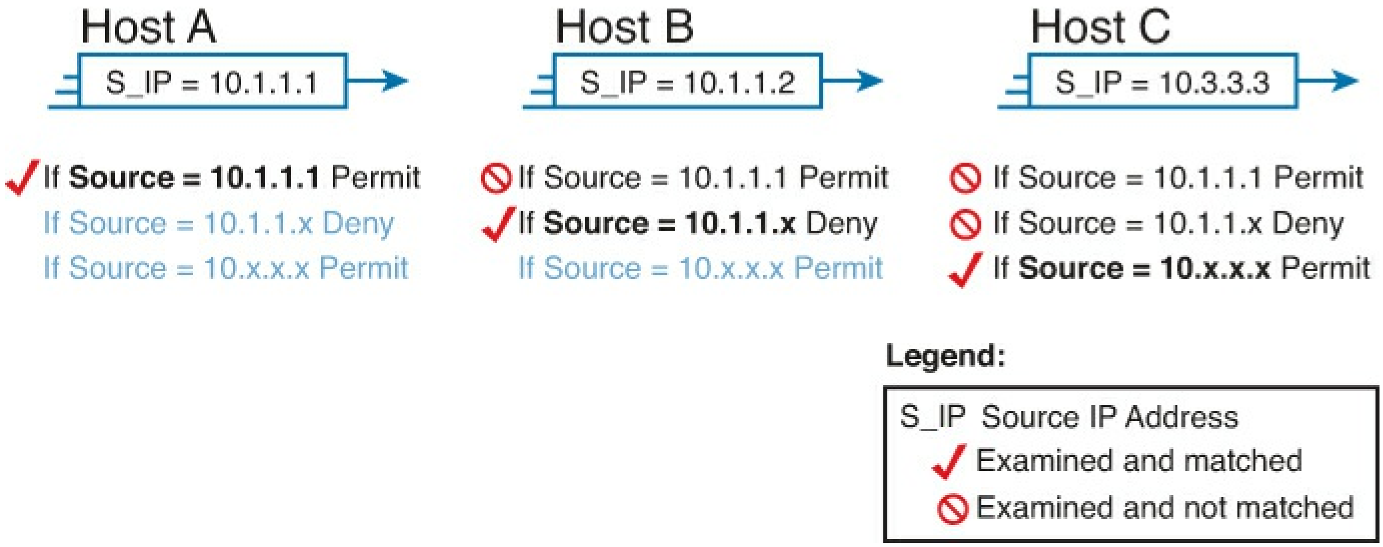

Host A
S_IP = 10.1.1.1
If Source = 10.1.1.1 Permit
If Source = 10.1.1.x Deny
If Source = 10.x.x.x Permit
Host B
S_IP = 10.1.1.2
If Source = 10.1.1.1 Permit
If Source = 10.1.1.x Deny
If Source = 10.x.x.x Permit
Host C
S_IP = 10.3.3.3
If Source = 10.1.1.1 Permit
If Source = 10.1.1.x Deny
If Source = 10.x.x.x Permit
Legend:
S_IP Source IP Address
Examined and matched
Examined and not matched

Figure 22-5. ACL Items Compared for Packets from Hosts A, B, and C in Figure 22-4

Next, consider a packet sent by host B, source IP address 10.1.1.2. When the packet enters R2's S0/0/1 interface, R2 compares the packet to ACL 1's first statement, and does not make a match (10.1.1.1 is not equal to 10.1.1.2). R2 then moves to the second statement, which requires some clarification. The ACL pseudocode, back in Figure 22-4, shows 10.1.1.x, which is meant to be shorthand that any value can exist in the last octet. Comparing only the first three octets, R2 decides that this latest packet does have a source IP address that begins with first three octets 10.1.1, so R2 considers that to be a match on the second statement. R2 takes the listed action (deny), discarding the packet. R2 also stops ACL processing on the packet, ignoring the third line in the ACL.

Finally, consider a packet sent by host C, again to server S1. The packet has source IP address 10.3.3.3, so when it enters R2's S0/0/1 interface, and drives ACL processing on R2, R2 looks at the first command in ACL 1. R2 does not match the first ACL command (10.1.1.1 in the command is not equal to the packet's 10.3.3.3). R2 looks at the second command, compares the first three octets (10.1.1) to the packet source IP address (10.3.3), still no match. R2 then looks at the third command. In this case, the wildcard means ignore the last three octets, and just compare the first octet (10), so the packet matches. R2 then takes the listed action (permit), allowing the packet to keep going.

This sequence of processing an ACL as a list happens for any type of IOS ACL: IP, other protocols, standard or extended, named or numbered.

Finally, if a packet does not match any of the items in the ACL, the packet is discarded. The reason is that every IP ACL has a *deny all* statement implied at the end of the ACL. It does not exist in the configuration, but if a router keeps searching the list, and no match is made by the end of the list, IOS considers the packet to have matched an entry that has a **deny** action.

Matching Logic and Command Syntax

Standard numbered IP ACLs use the following global command:

```
access-list {1-99 | 1300-1999} {permit | deny} matching-parameters
```

Each standard numbered ACL has one or more **access-list** commands with the same number, any number from the ranges shown in the preceding line of syntax. (One number is no better than the other.)

Besides the ACL number, each **access-list** command also lists the action (**permit** or **deny**), plus the matching logic. The rest of this section examines how to configure the matching parameters, which for standard ACLs, means that you can only match the source IP address, or portions of the source IP address using something called an ACL wildcard mask.

Matching the Exact IP Address

To match a specific source IP address, the entire IP address, all you have to do is type that IP address at the end of the command. For example, the previous example uses pseudocode for "permit if source = 10.1.1.1." The following command configures that logic with correct syntax using ACL number 1:

```
access-list 1 permit 10.1.1.1
```

Matching the exact full IP address is that simple.

In earlier IOS versions, the syntax included a **host** keyword. Instead of simply typing the full IP address, you first typed the **host** keyword, and then the IP address. Note that in later IOS versions, if you use the **host** keyword, IOS accepts the command, but then removes the keyword.

```
access-list 1 permit host 10.1.1.1
```

Matching a Subset of the Address with Wildcards

Often, the business goals you want to implement with an ACL does not match a single particular IP address, but rather a range of IP addresses. Maybe you want to match all IP addresses in a subnet. Maybe you want to match all IP addresses in a range of subnets, similar to a grouping you might want to collect into a route summary, like you did in Chapter 21, "Route Summarization." Regardless, you want to check for more than one IP address in a range of addresses.

IOS allows standard ACLs to match a range of addresses using a tool called a *wildcard mask*. Note that this is not a subnet mask. The wildcard mask (which this book abbreviates as *WC mask*) gives the engineer a way to tell IOS to ignore parts of the address when making comparisons, essentially treating those parts as wildcards, as if they already matched.

You can think about WC masks in decimal and in binary, and both have their uses. To begin, think about WC masks in decimal, using these rules:

Decimal 0: The router must compare this octet as normal.

Decimal 255: The router ignores this octet, considering it to already match.

Keeping these two rules in mind, consider Figure 22-6, which demonstrates this logic using three different but popular WC masks: one that tells the router to ignore the last octet, one that tells the router to ignore the last two octets, and one that tells the router to ignore the last three octets.

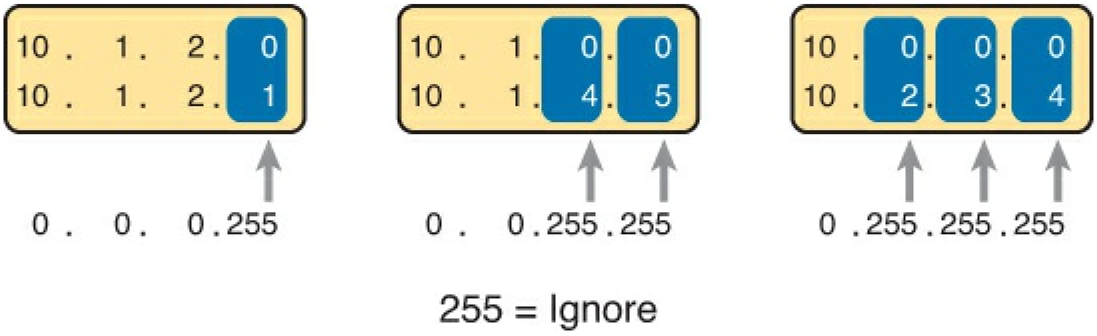


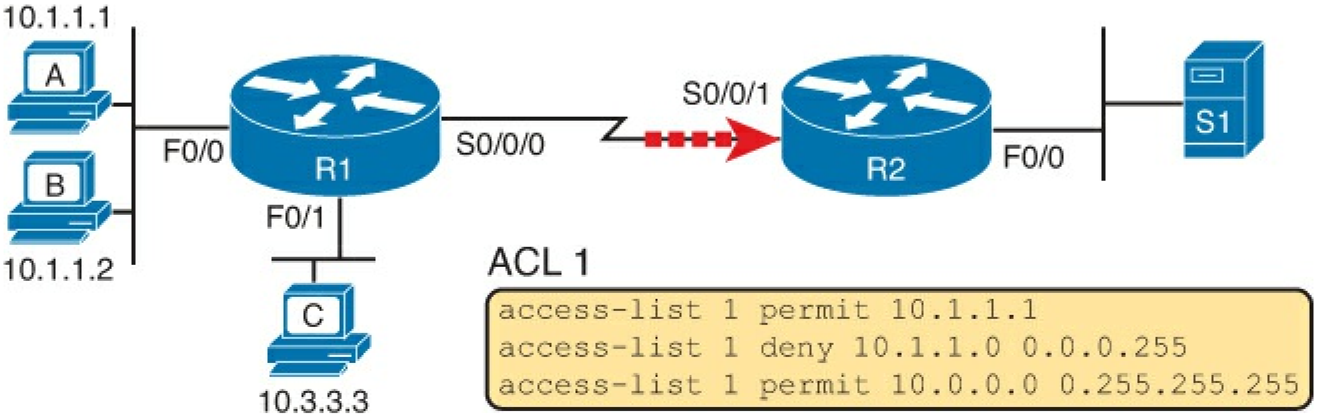
Figure 22-6. Logic for WC Masks 0.0.0.255, 0.0.255.255, and 0.255.255.255

All three examples in the boxes of Figure 22-6 show two numbers that are clearly different. The WC mask causes IOS to compare only some of the octets, while ignoring other octets. All three examples result in a match, because each wildcard mask tells IOS to ignore some octets. The example on the left shows WC mask 0.0.0.255, which tells the router to treat the last octet as a wildcard, essentially ignoring that octet for the comparison. Similarly, the middle example shows WC mask 0.0.255.255, which tells the router to ignore the two octets on the right. The rightmost case shows WC mask 0.255.255.255, telling the router to ignore the last three octets when comparing values.

To see the WC mask in action, think back to the earlier example related to Figure 22-4 and Figure 22-5. The pseudocode ACL in those two figures used logic that can be created using a WC mask. As a reminder, the logic in the pseudocode ACL in those two figures included the following:

- **Line 1:** Match and permit all packets with a source address of exactly 10.1.1.1.
- **Line 2:** Match and deny all packets with source addresses with first three octets 10.1.1.
- **Line 3:** Match and permit all addresses with first single octet 10.

Figure 22-7 shows the updated version of Figure 22-4, but with the completed, correct syntax, including the WC masks. In particular, note the use of WC mask 0.0.0.255 in the second command, telling R2 to ignore the last octet of the number 10.1.1.0, and the WC mask 0.255.255.255 in the third command, telling R2 to ignore the last three octets in the value 10.0.0.0.



```
access-list 1 permit 10.1.1.1
access-list 1 deny 10.1.1.0 0.0.0.255
access-list 1 permit 10.0.0.0 0.255.255.255
```

Figure 22-7. Syntactically Correct ACL Replaces Pseudocode from Figure 22-4

Finally, note that when using a WC mask, the **access-list** command's loosely defined *source* parameter should be a 0 in any octets where the WC mask is a 255. IOS will specify a source address to be 0 for the parts that will be ignored, even if nonzero values were configured.

Binary Wildcard Masks

Wildcard masks, as dotted-decimal number (DDN) values, actually represent a 32-bit binary number. As a 32-bit number, the WC mask actually directs the router's logic bit by bit. In short, a WC mask bit of 0 means the comparison should be done as normal, but a binary 1 means that the bit is a wildcard, and can be ignored when comparing the numbers.

Thankfully, for the purposes of CCENT and CCNA study and, frankly, for most real-world applications, you can ignore the binary WC mask. Why? Well, we generally want to match a range of addresses that can be easily identified by a subnet number and mask, whether it be a real subnet, or a summary route that groups subnets together. (See Chapter 21 for more on summary routes.) If you can describe the range of addresses with a subnet number and mask, you can find the numbers to use in your ACL with some simple math, as discussed next.

> **Note**
>
> If you really want to know the binary mask logic, take the two DDN numbers the ACL will compare (one from the **access-list** command, and the other from the packet header) and convert both to binary. Then, also convert the WC mask to binary. Compare the first two binary numbers bit by bit, but also ignore any bits for which the WC mask happens to list a binary 1, because that tells you to ignore the bit. If all the bits you checked are equal, it's a match!

Finding the Right Wildcard Mask to Match a Subnet

In many cases, an ACL needs to match all hosts in a particular subnet. To match a subnet with an ACL, you can use the following shortcut:

Key Topic

- Use the subnet number as the source value in the **access-list** command.
- Use a wildcard mask found by subtracting the subnet mask from 255.255.255.255.

For example, for subnet 172.16.8.0 255.255.252.0, use the subnet number (172.16.8.0) as the address parameter, and then do the following math to find the wildcard mask:

$$\begin{array}{r} 255.255.255.255 \\ -\ 255.255.252.0 \\ \hline 0.\quad 0.\quad 3.255 \end{array}$$

Continuing this example, a completed command for this same subnet would be as follows:

```
access-list 1 permit 172.16.8.0 0.0.3.255
```

The upcoming section, "Practice Applying Standard IP ACLs," gives you a chance to practice matching subnets when configuring ACLs.

Matching Any/All Addresses

In some cases, you will want one ACL command to match any and all packets that reach that point in the ACL. First, you have to know the (simple) way to match all packets using the **any** keyword. More importantly, you need to think about when to match any and all packets.

First, to match any and all packets with an ACL command, just use the **any** keyword for the address. For example, to permit all packets:

```
access-list 1 permit any
```

So, when and where should you use such a command? Remember, all Cisco IP ACLs end with an implicit deny any concept at the end of each ACL. That is, if a router compares a packet to the ACL, and the packet matches none of the configured statements, the router discards the packet. Want to override that default behavior? Configure a **permit any** at the end of the ACL.

You might also want to explicitly configure a command to deny all traffic (for example, **access-list 1 deny any**) at the end of an ACL. Why, when the same logic already sits at the end of the ACL anyway? Well, the ACL **show** commands list counters for the number of packets matched by each command in the ACL, but there is no counter for that implicit *deny any* concept at the end of the ACL. So, if you want to see counters for how many packets are matched by the *deny any* logic at the end of the ACL, configure an explicit **deny any**.

Implementing Standard IP ACLs

This chapter has already introduced all the configuration steps in bits and pieces. This section summarizes those pieces as a configuration process. The process also refers to the **access-list** command, whose generic syntax is repeated here for reference:

```
access-list access-list-number {deny | permit} source [source-wildcard]
```

Key Topic

Step 1. Plan the location (router and interface) and direction (in or out) on that interface:
  - **A.** Standard ACLs should be placed near to the destination of the packets so that they do not unintentionally discard packets that should not be discarded.
  - **B.** Because standard ACLs can only match a packet's source IP address, identify the source IP addresses of packets as they go in the direction that the ACL is examining.

Step 2. Configure one or more **access-list** global configuration commands to create the ACL, keeping the following in mind:
  - **A.** The list is searched sequentially, using first-match logic.
  - **B.** The default action, if a packet does not match any of the **access-list** commands, is to **deny** (discard) the packet.

Step 3. Enable the ACL on the chosen router interface, in the correct direction, using the **ip access-group** *number* {**in | out**} interface subcommand.

The rest of this section shows a couple of examples.

Standard Numbered ACL Example 1

The first example shows the configuration for the same requirements demonstrated with Figure 22-4 and Figure 22-5. Restated, the requirements for this ACL are as follows:

1. Enable the ACL inbound on R2's S0/0/1 interface.
2. Permit packets coming from host A.
3. Deny packets coming from other hosts in host A's subnet.
4. Permit packets coming from any other address in Class A network 10.0.0.0.
5. The original example made no comment about what to do by default, so simply deny all other traffic.

Example 22-1 shows a completed correct configuration, starting with the configuration process, followed by output from the **show running-config** command.

Example 22-1. Standard Numbered ACL Example 1 Configuration

Click here to view code image

```
R2# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R2(config)# access-list 1 permit 10.1.1.1
R2(config)# access-list 1 deny 10.1.1.0 0.0.0.255
R2(config)# access-list 1 permit 10.0.0.0 0.255.255.255
R2(config)# interface S0/0/1
R2(config-if)# ip access-group 1 in
R2(config-if)# ^Z
R2# show running-config
! Lines omitted for brevity

access-list 1 permit 10.1.1.1
access-list 1 deny 10.1.1.0 0.0.0.255
access-list 1 permit 10.0.0.0 0.255.255.255
```

First, pay close attention to the configuration process at the top of the example. Note that the **access-list** command does not change the command prompt from the global configuration mode prompt, because the **access-list** command is a global configuration command. Then, compare that to the output of the **show running-config** command: the details are identical compared to the commands that were added in configuration mode. Finally, make sure to note the **ip access-group 1 in** command, under R2's S0/0/1 interface, which enables the ACL logic (both location and direction).

Example 22-2 lists some output from Router R2 that shows information about this ACL. The **show ip access-lists** command lists details about IPv4 ACLs only, while the **show access-lists** command lists details about IPv4 ACLs plus any other types of ACLs that are currently configured, for example, IPv6 ACLs.

Example 22-2. ACL show **Commands on R2**

Click here to view code image

```
R2# show ip access-lists
Standard IP access list 1
10 permit 10.1.1.1 (107 matches)
20 deny 10.1.1.0, wildcard bits 0.0.0.255 (4 matches)
30 permit 10.0.0.0, wildcard bits 0.255.255.255 (10 matches)
R2# show access-lists
Standard IP access list 1
10 permit 10.1.1.1 (107 matches)
20 deny 10.1.1.0, wildcard bits 0.0.0.255 (4 matches)
30 permit 10.0.0.0, wildcard bits 0.255.255.255 (10 matches)
R2# show ip interface s0/0/1
Serial0/0/1 is up, line protocol is up
Internet address is 10.1.2.2/24
Broadcast address is 255.255.255.255
Address determined by setup command
MTU is 1500 bytes
Helper address is not set
Directed broadcast forwarding is disabled
Multicast reserved groups joined: 224.0.0.9
Outgoing access list is not set
Inbound access list is 1
! Lines omitted for brevity
```

The output of these commands shows two items of note. The first line of output in this case notes the type (standard), and the number. If more than one ACL existed, you would see multiple stanzas of output, one per ACL, each with a heading line like this one. Next, these commands list packet counts for the number of packets that the router has matched with each command. For example, 107 packets so far have matched the first line in the ACL.

Finally, the end of the example lists the **show ip interface** command output. This command lists, among many other items, the number or name of any IP ACL enabled on the interface per the **ip access-group** interface subcommand.

Standard Numbered ACL Example 2

For the second example, use Figure 22-8, and imagine your boss gave you some requirements hurriedly in the hall. At first, he tells you he wants to filter packets going from the servers on the right toward the clients on the left. Then, he says he wants you to allow access for hosts A, B, and other hosts in their same subnet to server S1, but deny access to that server to the hosts in host C's subnet. Then, he tells you that, additionally, hosts in host A's subnet should be denied access to server S2, but hosts in host C's subnet should be allowed access to server S2. All by filtering packets going right to left only, and then he tells you: put the ACL inbound on R2's F0/0 interface.

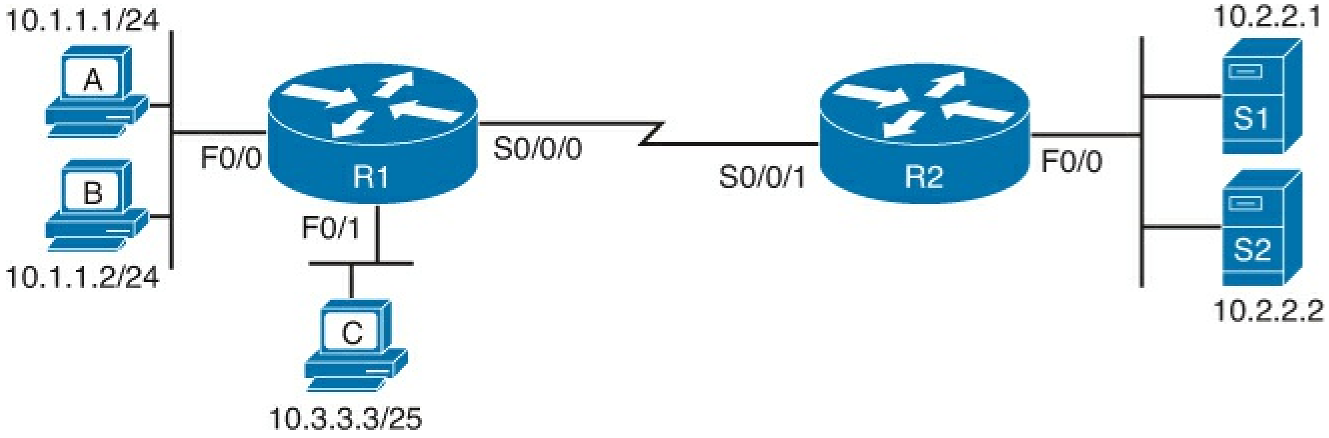


Figure 22-8. Standard Numbered ACL Example 2

If you cull through all the boss's comments, the requirements might reduce to the following:

1. Enable the ACL inbound on R2's F0/0 interface.
2. Permit packets from server S1 going to hosts in A's subnet.
3. Deny packets from server S1 going to hosts in C's subnet.
4. Permit packets from server S2 going to hosts in C's subnet.
5. Deny packets from server S2 going to hosts in A's subnet.
6. (There was no comment about what to do by default; use the implied **deny all** default.)

As it turns out, you cannot do everything your boss asked with a standard ACL. For example, consider the obvious command for requirement number 2: **access-list 2 permit 10.2.2.1**. That permits all traffic whose source IP is 10.2.2.1 (server S1). The very next requirement asks you to filter (deny) packets sourced from that same IP address! Even if you added another command that checked for source IP address 10.2.2.1, the router would never get to it, because routers use first-match logic when searching the ACL. You cannot check both the destination and source IP address, because standard ACLs cannot check the destination IP address.

To solve this problem, you should get a new boss! No, seriously, you have to rethink the problem and change the rules. In real life, you would probably use an extended ACL instead, as discussed in Chapter 23, which lets you check both the source and destination IP address.

For the sake of practicing another standard ACLs, imagine your boss lets you change the requirements. First, you will use two outbound ACLs, both on Router R1. Each ACL will permit traffic from a single server to be forwarded onto that connected LAN, with the following modified requirements:

1. Using an outbound ACL on R1’s F0/0 interface, permit packets from server S1, and deny all other packets.
2. Using an outbound ACL on R1’s F0/1 interface, permit packets from server S2, and deny all other packets.

Example 22-3 shows the configuration that completes these requirements.

Example 22-3. Alternative Configuration in Router R1

Click here to view code image

```
access-list 2 remark This ACL permits server S1 traffic to host A's subnet
access-list 2 permit 10.2.2.1
!
access-list 3 remark This ACL permits server S2 traffic to host C's subnet
access-list 3 permit 10.2.2.2
!
interface F0/0
ip access-group 2 out
!
interface F0/1
ip access-group 3 out
```

As highlighted in the example, the solution with ACL number 2 permits all traffic from server S1, with that logic enabled for packets exiting R1’s F0/0 interface. All other traffic will be discarded because of the implied deny all at the end of the ACL. Additionally, ACL 3 permits traffic from server S2, which is then permitted to exit R1’s F0/1 interface. Also, note that the solution shows the use of the **access-list remark** parameter, which allows you to leave text documentation that stays with the ACL.

Note

When routers apply an ACL to filter packets in the outbound direction, as shown in Example 22-3, the router checks packets that it routes against the ACL. However, a router does not filter packets that the router itself creates with an outbound ACL. Examples of those packets include OSPF routing protocol messages, and packets sent by the **ping** and **traceroute** commands on that router.

Troubleshooting and Verification Tips

Troubleshooting IPv4 ACLs requires some attention to detail. In particular, you have to be ready to look at the address and wildcard mask and confidently predict the addresses matched by those two combined parameters. The upcoming practice problems a little later in this chapter can help prepare you for that part of the work. But a few other tips can help you verify and troubleshoot ACL problems on the exams as well.

First, you can tell if the router is matching packets or not with a couple of tools. Example 22-2 already showed that IOS keeps statistics about the packets matched by each line of an ACL. Additionally, if you add the **log** keyword to the end of an **access-list** command, IOS then issues log messages with occasional statistics about matches of that particular line of the ACL. Both the statistics and the log messages can be helpful in deciding which line in the ACL is being matched by a packet.

For example, Example 22-4 shows an updated version of ACL 2 from Example 22-3, this time with the **log** keyword added. The bottom of the example then shows a typical log message, this one showing the resulting match based on a packet with source IP address 10.2.2.1 (as matched with the ACL), to destination address 10.1.1.1.

Example 22-4. Creating Log Messages for ACL Statistics

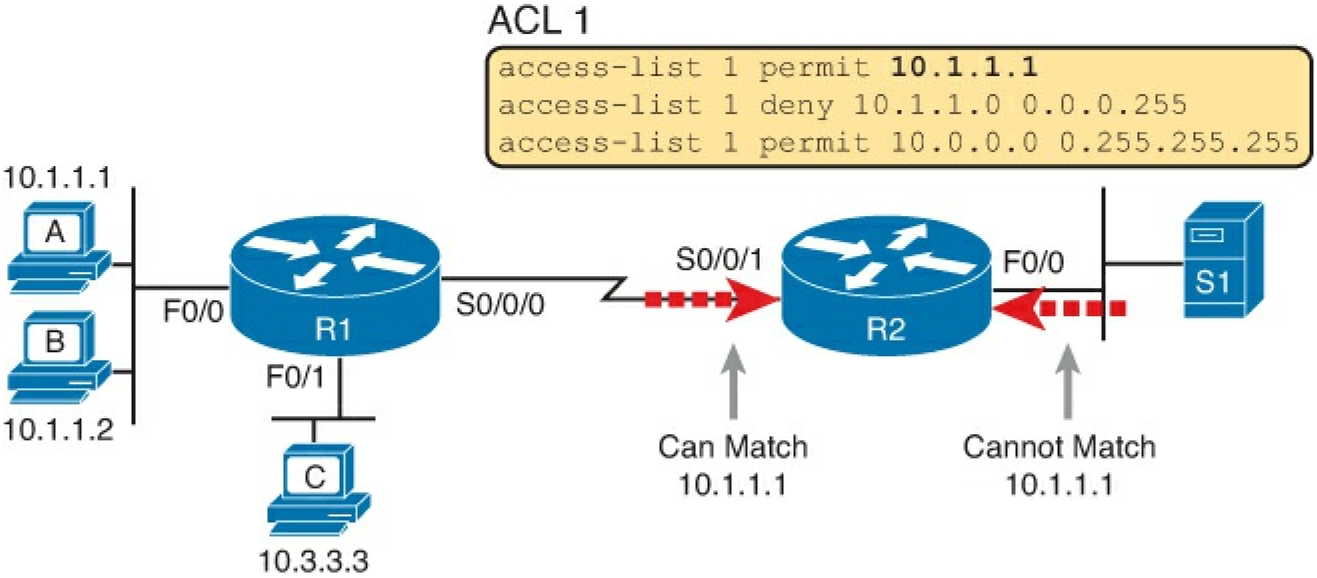
Click here to view code image

```
R1# show running-config
! lines removed for brevity
access-list 2 remark This ACL permits server S1 traffic to host A's subnet
access-list 2 permit 10.2.2.1 log
```

```
!
interface F0/0
ip access-group 2 out
R1#

Feb 4 18:30:24.082: %SEC-6-IPACCESSLOGNP: list 2 permitted 0 10.2.2.1 -> 10.1.1.1, 1 packet
```

Anytime you troubleshoot an ACL for the first time, before getting into the details of the matching logic, take the time to think about both the interface on which the ACL is enabled, and the direction of packet flow. Sometimes, the matching logic is perfect—but the ACL has been enabled on the wrong interface, or for the wrong direction, to match the packets as configured for the ACL.

For example, Figure 22-9 repeats the same ACL shown earlier in Figure 22-7. The first line of that ACL matches the specific host address 10.1.1.1. If that ACL exists on router R2, placing that ACL as an inbound ACL on R2's S0/0/1 interface can work, because packets sent by host 10.1.1.1—on the left side of the figure—can enter R2's S0/0/1 interface. However, if R2 enables ACL 1 on it F0/0 interface, for inbound packets, the ACL will never match a packet with source IP address 10.1.1.1, because packets sent by host 10.1.1.1 will never enter that interface. Packets sent by 10.1.1.1 will exit R2's F0/0 interface, but never enter it, just because of the network topology.



```
access-list 1 permit 10.1.1.1
access-list 1 deny 10.1.1.0 0.0.0.255
access-list 1 permit 10.0.0.0 0.255.255.255
```

Figure 22-9. Example of Checking the Interface and Direction for an ACL

Practice Applying Standard IP ACLs

Some CCENT and CCNA topics, like subnetting, simply require more drills and practice than others. You can also benefit from doing practice drills with ACLs in part because ACLs require you to think of parameters to match ranges of numbers, and that of course requires some use of math, and some use of processes.

This section provides some practice problems and tips, from two perspectives. First, this section asks you to build one-line standard ACLs to match some packets. Second, this section asks you to interpret existing ACL commands to describe what packets the ACL will match. Both skills are useful for the exams.

Practice Building access-list Commands

In this section, practice getting comfortable with the syntax of the **access-list** command, particularly with choosing the correct matching logic. These skills will be helpful when reading about extended and named ACLs in the next chapter.

First, the following list summarizes some important tips to consider when choosing matching parameters to any **access-list** command:

Key Topic

- To match a specific address, just list the address.
- To match any and all addresses, use the **any** keyword.
- To match based only on the first one, two, or three octets of an address, use the 0.255.255.255, 0.0.255.255, and 0.0.0.255 WC masks, respectively. Also, make the source (address) parameter have 0s in the wildcard octets (those octets with 255 in the wildcard mask).
- To match a subnet, use the subnet ID as the source, and find the WC mask by subtracting the DDN subnet mask from 255.255.255.255.

Table 22-2 lists the criteria for several practice problems. Your job: Create a one-line standard ACL that matches the packets. The answers are listed in the section, "Answers to Earlier Practice Problems," later in this chapter.

Table 22-2. Building One-Line Standard ACLs: Practice

Problem	Criteria
1	Packets from 172.16.5.4
2	Packets from hosts with 192.168.6 as the first three octets
3	Packets from hosts with 192.168 as the first two octets
4	Packets from any host
5	Packets from subnet 10.1.200.0/21
6	Packets from subnet 10.1.200.0/27
7	Packets from subnet 172.20.112.0/23
8	Packets from subnet 172.20.112.0/26
9	Packets from subnet 192.168.9.64/28
10	Packets from subnet 192.168.9.64/30

Reverse Engineering from ACL to Address Range

Some exam questions might not ask that you pick the ACL statement that needs to be configured, instead asking that you interpret some existing **access-list** commands. To answer these types of questions, you need to determine the range of IP addresses matched by a particular address/wildcard mask combination in each ACL statement.

Key Topic

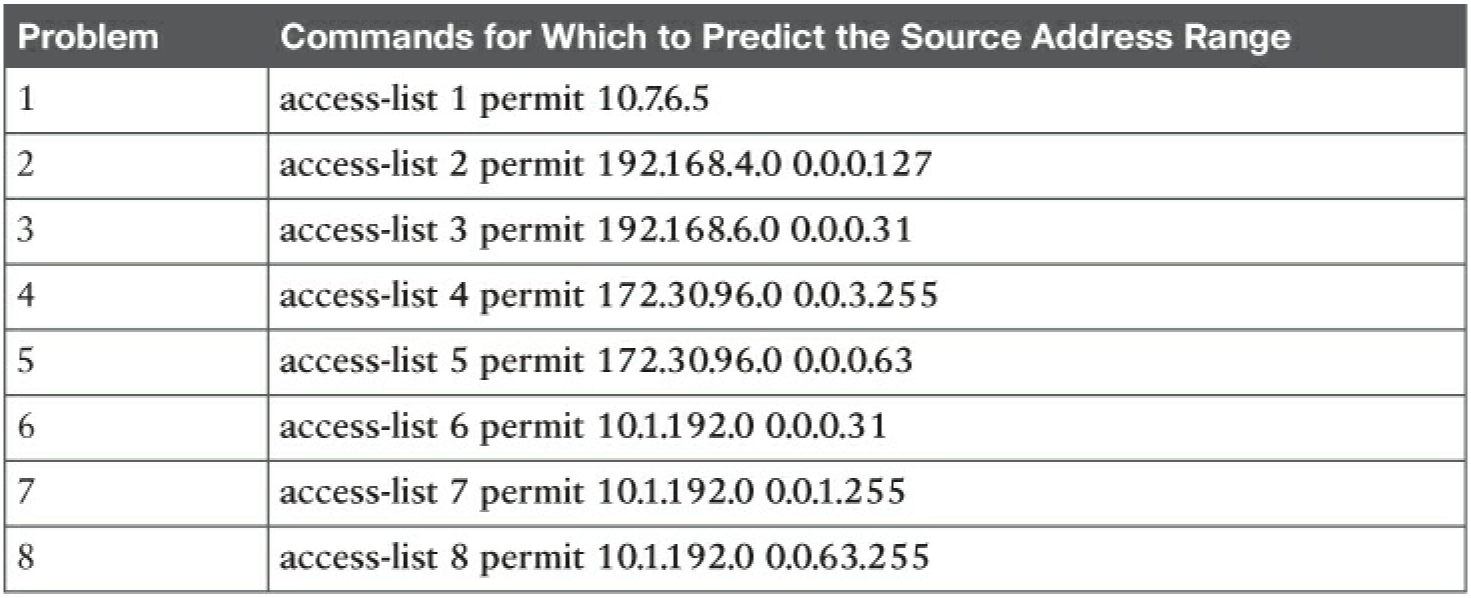
Under certain assumptions that are reasonable for CCENT and CCNA, calculating the range of addresses matched by an ACL can be relatively simple. The low end of the range is the address field, and you find the high end of the range by adding the address to the WC mask. That's it.

For example, with the command **access-list 1 permit 172.16.200.0 0.0.7.255**, the low end of the range is simply 172.16.200.0, taken directly from the command itself. Then, to find the high end of the range, just add this number to the WC mask, as follows:

```
  172.16.200.0
+  0. 0.  7.255
---------------
  172.16.207.255
```

For this last bit of practice, look at the existing **access-list** commands in Table 22-3. In each case, make a notation about the exact IP address, or range of IP addresses, matched by the command.

Table 22-3. Finding IP Addresses/Ranges Matching by Existing ACLs



Problem	Commands for Which to Predict the Source Address Range
1	access-list 1 permit 10.7.6.5
2	access-list 2 permit 192.168.4.0 0.0.0.127
3	access-list 3 permit 192.168.6.0 0.0.0.31
4	access-list 4 permit 172.30.96.0 0.0.3.255
5	access-list 5 permit 172.30.96.0 0.0.0.63
6	access-list 6 permit 10.1.192.0 0.0.0.31
7	access-list 7 permit 10.1.192.0 0.0.1.255
8	access-list 8 permit 10.1.192.0 0.0.63.255

Interestingly, IOS lets the CLI user type an **access-list** command in configuration mode, and IOS will potentially change the address parameter before placing the command into the running config file. This process of just finding the range of addresses matched by the **access-list** command expects that the **access-list** command came from the router, so that any such changes were complete.

The change IOS can make with an **access-list** command is to convert to 0 any octet of an address for which the wildcard mask's octet is 255. For example, with a wildcard mask of 0.0.255.255, IOS ignores the last two octets. IOS expects the address field to end with two 0s. If not, IOS still accepts the **access-list** command, but IOS changes the last two octets of the address to 0s. Example 22-5 shows an example, where the configuration shows address 10.1.1.1, but wildcard mask 0.0.255.255.

Example 22-5. IOS Changing the Address Field in an access-list **Command**

Click here to view code image

```
R2# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R2(config)# access-list 21 permit 10.1.1.1 0.0.255.255
R2(config)# ^Z
R2#
R2# show ip access-lists
Standard IP access list 21
10 permit 10.1.0.0, wildcard bits 0.0.255.255
```

The math to find the range of addresses relies on the fact that either the command is fully correct, or that IOS has already set these address octets to 0, as shown in the example.

Note

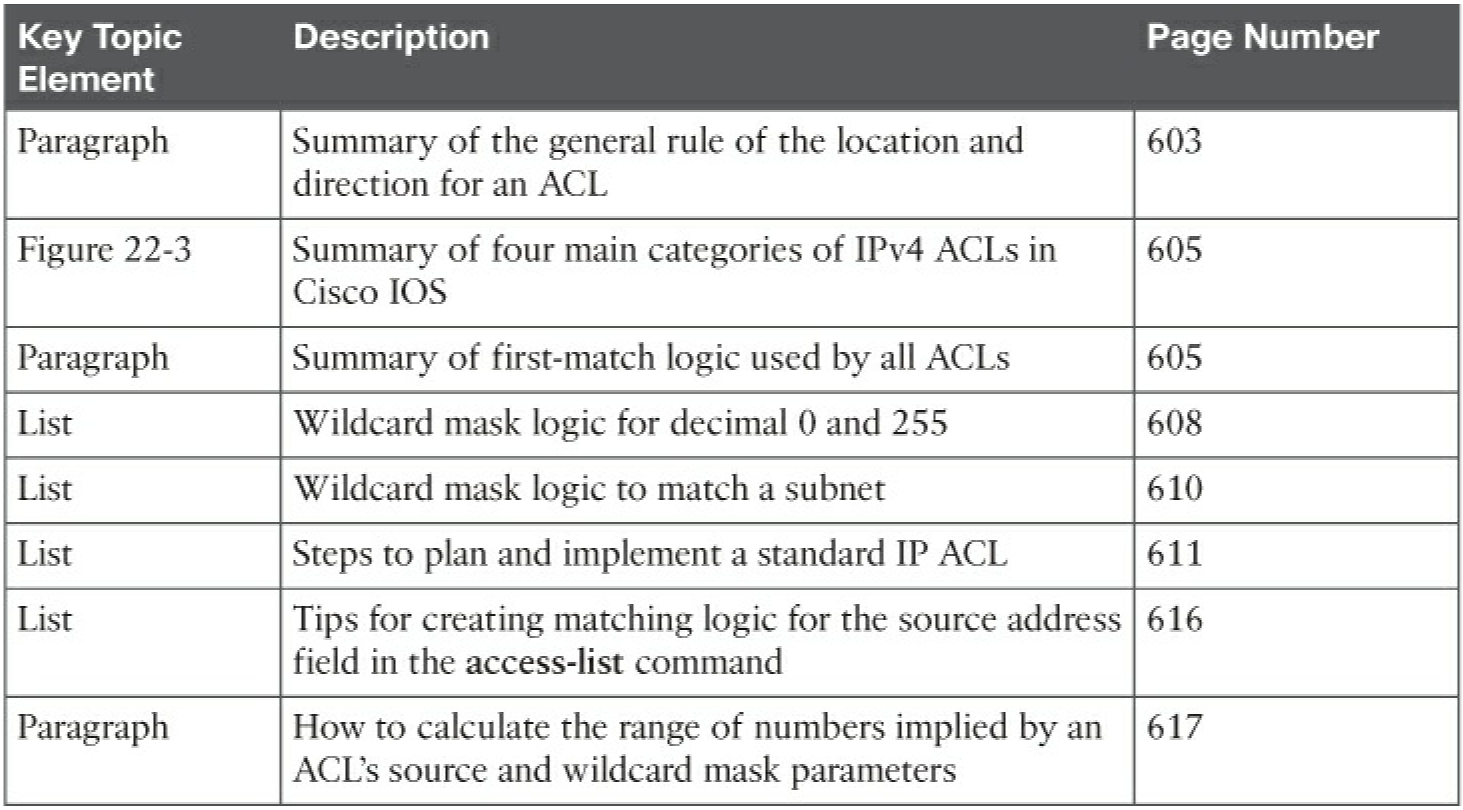
The most useful WC masks, in binary, do not interleave 0s and 1s. This book assumes the use of only these types of WC masks. However, WC masks that interleave 0s and 1s are allowed, but these WC masks break the simple method of calculating the range of addresses. As you progress through to CCIE studies, be ready to dig deeper to learn how to determine what an ACL matches.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 22-4 lists these key topics and where each is discussed.

Table 22-4. Key Topics for Chapter 22



Key Topic Element	Description	Page Number
Paragraph	Summary of the general rule of the location and direction for an ACL	603
Figure 22-3	Summary of four main categories of IPv4 ACLs in Cisco IOS	605
Paragraph	Summary of first-match logic used by all ACLs	605
List	Wildcard mask logic for decimal 0 and 255	608
List	Wildcard mask logic to match a subnet	610
List	Steps to plan and implement a standard IP ACL	611
List	Tips for creating matching logic for the source address field in the **access-list** command	616
Paragraph	How to calculate the range of numbers implied by an ACL's source and wildcard mask parameters	617

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

standard access list
wildcard mask

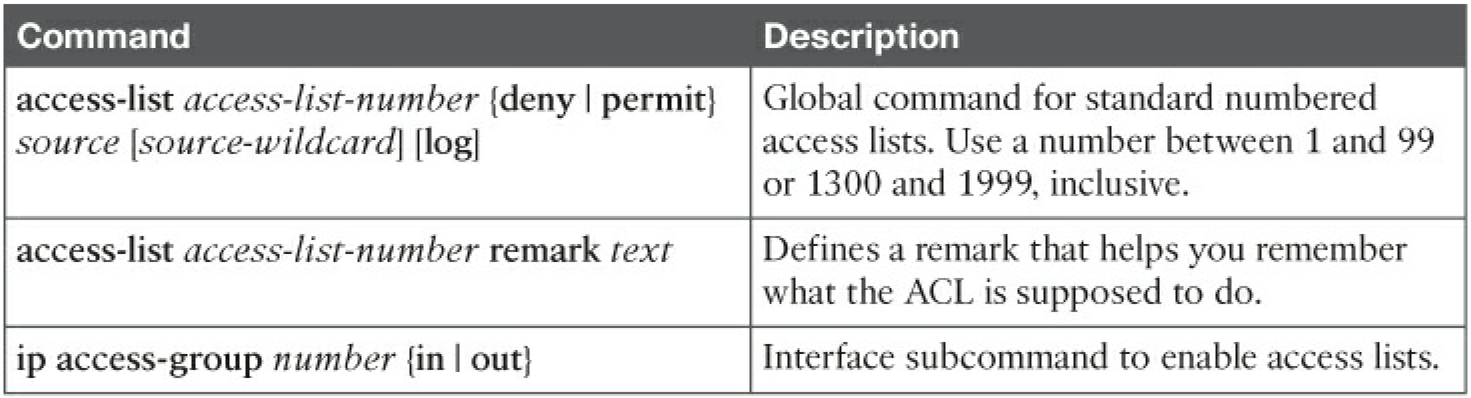
Appendix J Practice Problems

DVD Appendix J, "Practice for Chapter 22: Basic IPv4 Access Control Lists," lists additional practice problems and answers.

Command Reference to Check Your Memory

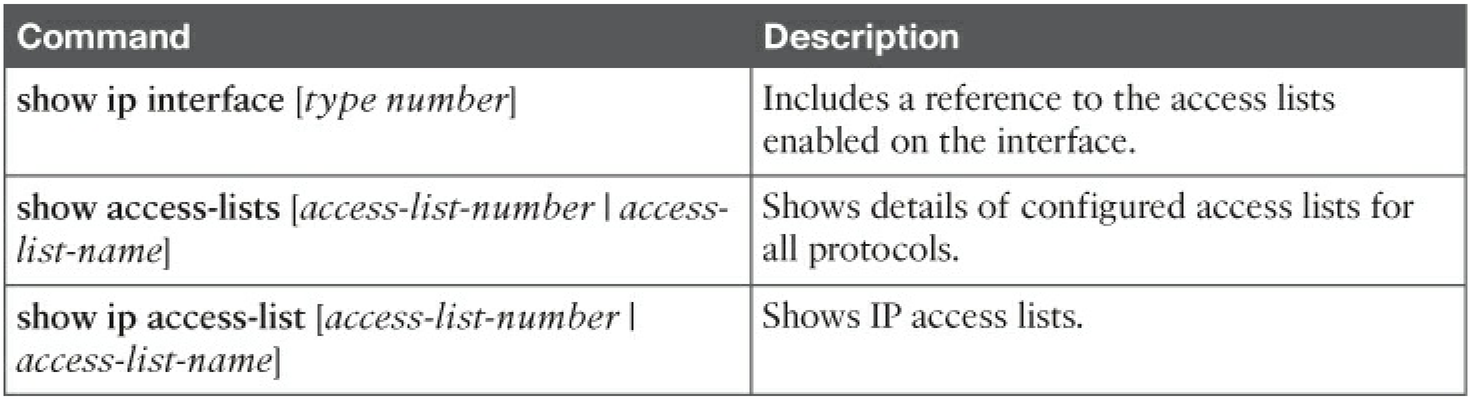
Although you should not necessarily memorize the information in the tables in this section, this section includes a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading this chapter and doing all the activities in this "Exam Preparation" section. To see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table, read the descriptions on the right side, and see if you remember the command.

Table 22-5. Chapter 22 Configuration Command Reference



Command	Description
access-list *access-list-number* {**deny** | **permit**} *source* [*source-wildcard*] [**log**]	Global command for standard numbered access lists. Use a number between 1 and 99 or 1300 and 1999, inclusive.
access-list *access-list-number* **remark** *text*	Defines a remark that helps you remember what the ACL is supposed to do.
ip access-group *number* {**in** | **out**}	Interface subcommand to enable access lists.

Table 22-6. Chapter 22 EXEC Command Reference

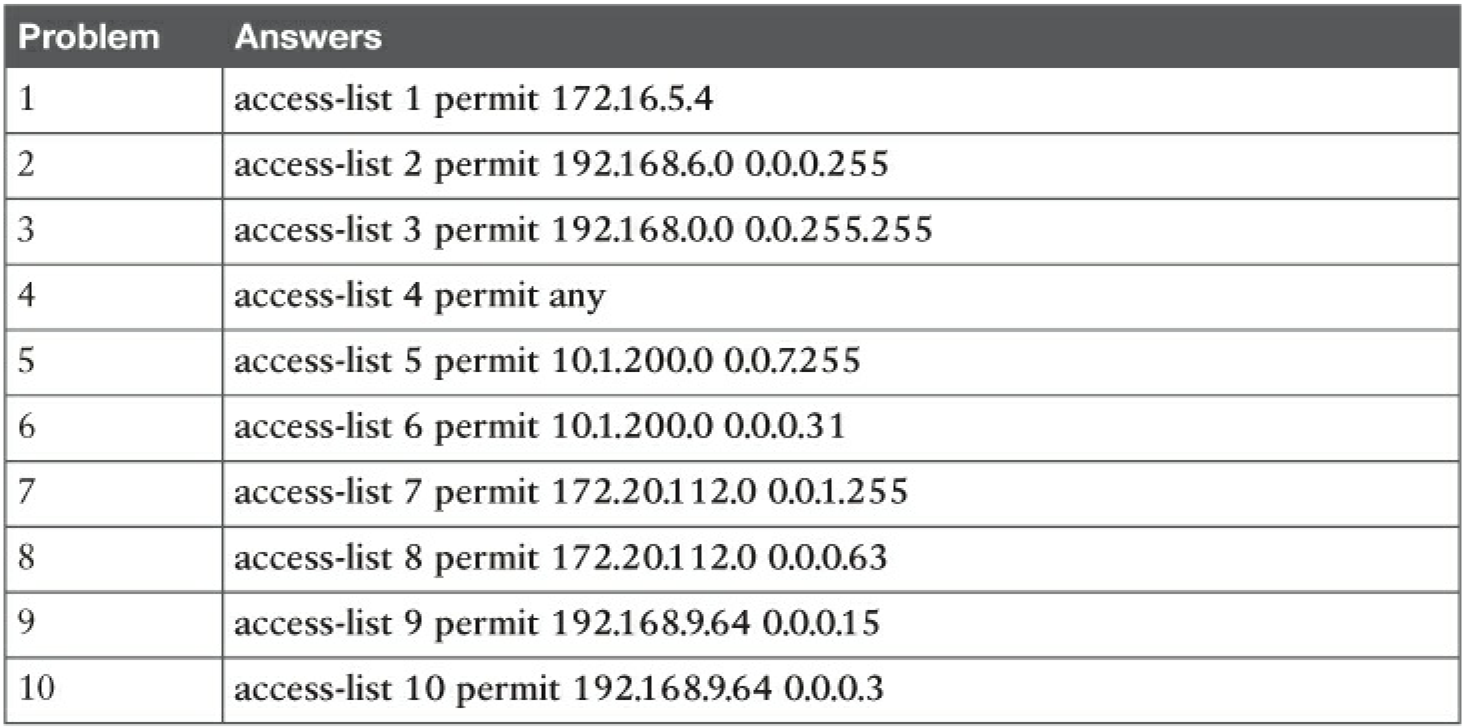


Command	Description
show ip interface [*type number*]	Includes a reference to the access lists enabled on the interface.
show access-lists [*access-list-number* | *access-list-name*]	Shows details of configured access lists for all protocols.
show ip access-list [*access-list-number* | *access-list-name*]	Shows IP access lists.

Answers to Earlier Practice Problems

Table 22-7 lists the answers to the problems listed earlier in Table 22-2.

Table 22-7. Building One-Line Standard ACLs: Answers



Problem	Answers
1	access-list 1 permit 172.16.5.4
2	access-list 2 permit 192.168.6.0 0.0.0.255
3	access-list 3 permit 192.168.0.0 0.0.255.255
4	access-list 4 permit any
5	access-list 5 permit 10.1.200.0 0.0.7.255
6	access-list 6 permit 10.1.200.0 0.0.0.31
7	access-list 7 permit 172.20.112.0 0.0.1.255
8	access-list 8 permit 172.20.112.0 0.0.0.63
9	access-list 9 permit 192.168.9.64 0.0.0.15
10	access-list 10 permit 192.168.9.64 0.0.0.3

Table 22-8 lists the answers to the problems listed earlier in Table 22-3.

Table 22-8. Address Ranges for Problems in Table 22-3: Answers

Problem	Address Range
1	One address: 10.7.6.5
2	192.168.4.0–192.168.4.127
3	192.168.6.0–192.168.6.31
4	172.30.96.0–172.30.99.255
5	172.30.96.0–172.30.96.63
6	10.1.192.0–10.1.192.31
7	10.1.192.0–10.1.193.255
8	10.1.192.0–10.1.255.255

Chapter 23. Advanced IPv4 ACLs and Device Security

This chapter covers the following exam topics:

IP Services

- Describe the types, features, and applications of ACLs
  - Sequence numbers
  - Editing
  - Extended
  - Named
  - Numbered
- Configure and verify ACLs in a network environment
  - Named
  - Numbered
- Configure and verify NTP as a client

Network Device Security

- Configure and verify network device security features such as
  - Transport
  - Disable telnet
  - Physical security
  - Setting native VLAN to other than VLAN 1
- Configure and verify ACLs to filter network traffic
- Configure and verify an ACL to limit telnet and SSH access to the router
- Troubleshoot and Resolve ACL issues
  - Statistics
  - Permitted networks
  - Direction
  - Interface

Cisco routers use IPv4 access control lists (ACL) for many different applications: to match packets to make filtering decisions, to match packets for Network Address Translation (NAT), to match packets to make quality of service (QoS) decisions, and for several other reasons.

Most IP ACLs are either standard or extended ACLs, with standard ACLs matching only the source IP address, and extended matching a variety of packet header fields. At the same time, IP ACLs are either numbered or named. Figure 23-1 shows the categories, and the main features of each, as introduced in the previous chapter.

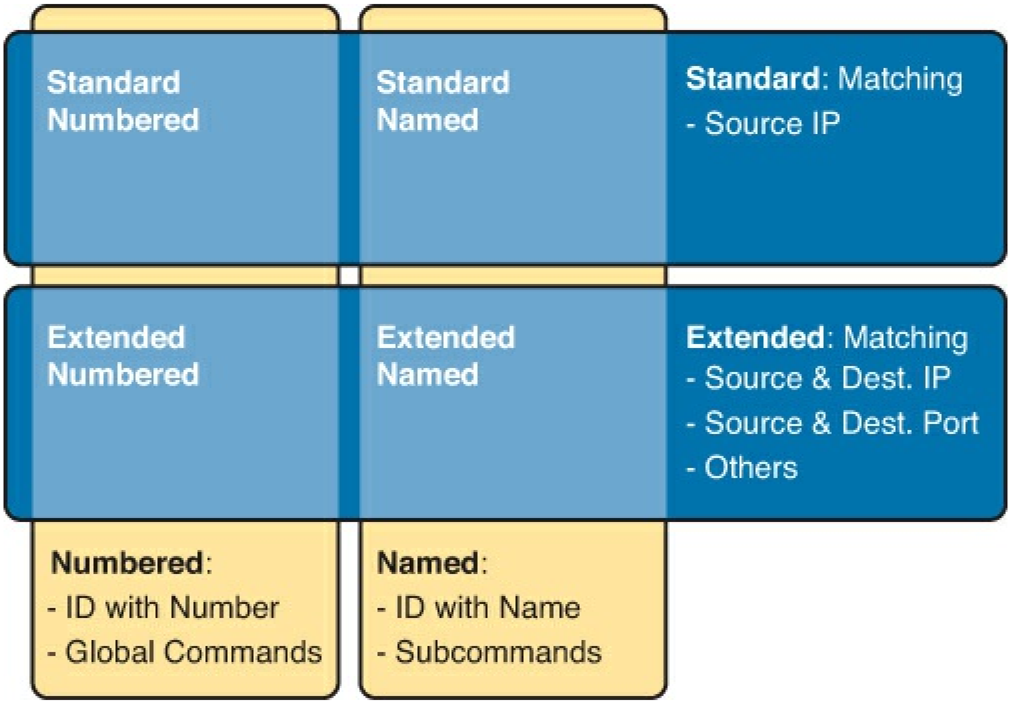

Standard Numbered
Standard Named
Standard: Matching
- Source IP
Extended Numbered
Extended Named
Extended: Matching
- Source & Dest. IP
- Source & Dest. Port
- Others
Numbered:
- ID with Number
- Global Commands
Named:
- ID with Name
- Subcommands

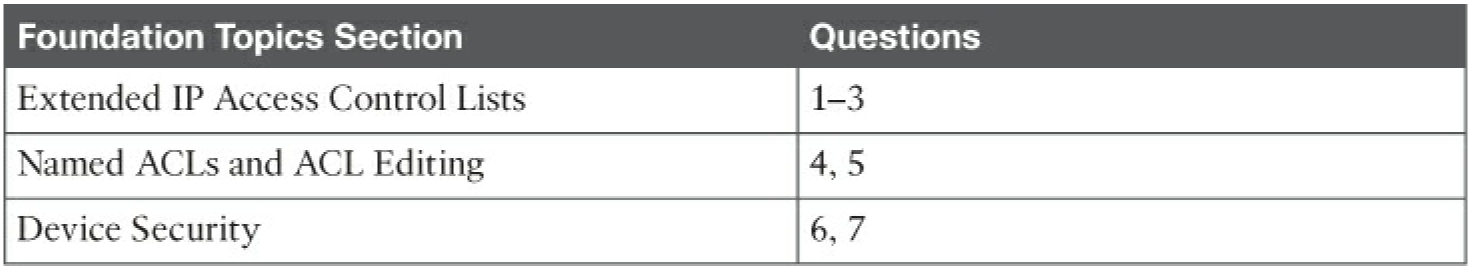
Figure 23-1. Comparisons of IP ACL Types

This chapter discusses the other three categories of ACLs beyond standard numbered IP ACLs, and ends with a few miscellaneous features to secure Cisco routers and switches.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 23-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Extended IP Access Control Lists	1–3
Named ACLs and ACL Editing	4, 5
Device Security	6, 7

1. Which of the following fields cannot be compared based on an extended IP ACL? (Choose two answers.)
   - **a.** Protocol
   - **b.** Source IP address
   - **c.** Destination IP address
   - **d.** TOS byte
   - **e.** URL
   - **f.** Filename for FTP transfers
2. Which of the following **access-list** commands permit packets going from host 10.1.1.1 to all web servers whose IP addresses begin with 172.16.5? (Choose two answers.)
   - **a. access-list 101 permit tcp host 10.1.1.1 172.16.5.0 0.0.0.255 eq www**
   - **b. access-list 1951 permit ip host 10.1.1.1 172.16.5.0 0.0.0.255 eq www**
   - **c. access-list 2523 permit ip host 10.1.1.1 eq www 172.16.5.0 0.0.0.255**
   - **d. access-list 2523 permit tcp host 10.1.1.1 eq www 172.16.5.0 0.0.0.255**
   - **e. access-list 2523 permit tcp host 10.1.1.1 172.16.5.0 0.0.0.255 eq www**
3. Which of the following **access-list** commands permits packets going to any web client from all web servers whose IP addresses begin with 172.16.5?
   - **a. access-list 101 permit tcp host 10.1.1.1 172.16.5.0 0.0.0.255 eq www**
   - **b. access-list 1951 permit ip host 10.1.1.1 172.16.5.0 0.0.0.255 eq www**
   - **c. access-list 2523 permit tcp any eq www 172.16.5.0 0.0.0.255**
   - **d. access-list 2523 permit tcp 172.16.5.0 0.0.0.255 eq www 172.16.5.0 0.0.0.255**
   - **e. access-list 2523 permit tcp 172.16.5.0 0.0.0.255 eq www any**
4. Which of the following fields can be compared using a named extended IP ACL but not a numbered extended IP ACL?
   - **a.** Protocol
   - **b.** Source IP address
   - **c.** Destination IP address
   - **d.** TOS byte
   - **e.** None of the other answers are correct.
5. In a router running a recent IOS version (at least version 15.0), an engineer needs to delete the second line in ACL 101, which currently has four commands configured. Which of the following options could be used? (Choose two answers.)
   - **a.** Delete the entire ACL and reconfigure the three ACL statements that should remain in the ACL.
   - **b.** Delete one line from the ACL using the **no access-list...** global command.
   - **c.** Delete one line from the ACL by entering ACL configuration mode for the ACL and then deleting only the second line based on its sequence number.
   - **d.** Delete the last three lines from the ACL from global configuration mode, and then add the last two statements back into the ACL.
6. What general guideline should you follow when placing extended IP ACLs?
   - **a.** Perform all filtering on output if at all possible.
   - **b.** Put more general statements early in the ACL.
   - **c.** Filter packets as close to the source as possible.
   - **d.** Order the ACL commands based on the source IP addresses, from lowest to highest, to improve performance.
7. Which of the following is accurate about the NTP client function on a Cisco router?

a. The client synchronizes its time-of-day clock based on the NTP server.
b. It counts CPU cycles of the local router CPU to more accurately keep time.
c. The client synchronizes its serial line clock rate based on the NTP server.
d. The client must be connected to the same subnet as an NTP server.

Answers to the "Do I Know This Already?" quiz:

1 E and F **2** A and E **3** E **4** E **5** A and C **6** C **7** A

Foundation Topics

Extended Numbered IP Access Control Lists

Extended IP access lists have many similarities compared to the standard numbered IP ACLs discussed in the previous chapter. Just like standard IP ACLs, you enable extended access lists on interfaces for packets either entering or exiting the interface. IOS searches the list sequentially. Extended ACLs also use first-match logic, because the router stops the search through the list as soon as the first statement is matched, taking the action defined in the first-matched statement. All these features are also true of standard numbered access lists (and named ACLs).

Extended ACLs differ from standard ACLs mostly because of the larger variety of packet header fields that can be used to match a packet. One extended ACL statement can examine multiple parts of the packet headers, requiring that all the parameters be matched correctly to match that one ACL statement. That powerful matching logic makes extended access lists both more useful and more complex than standard IP ACLs.

Matching the Protocol, Source IP, and Destination IP

Like standard numbered IP ACLs, extended numbered IP ACLs also use the **access-list** global command. The syntax is identical, at least up through the **permit** or **deny** keyword. At that point, the command lists matching parameters, and those differ, of course. In particular, the extended ACL **access-list** command requires three matching parameters: the IP protocol type, the source IP address, and the destination IP address.

The IP header's Protocol field identifies the header that follows the IP header. Figure 23-2 shows the location of the IP Protocol field, the concept of it pointing to the type of header that follows, along with some details of the IP header for reference.

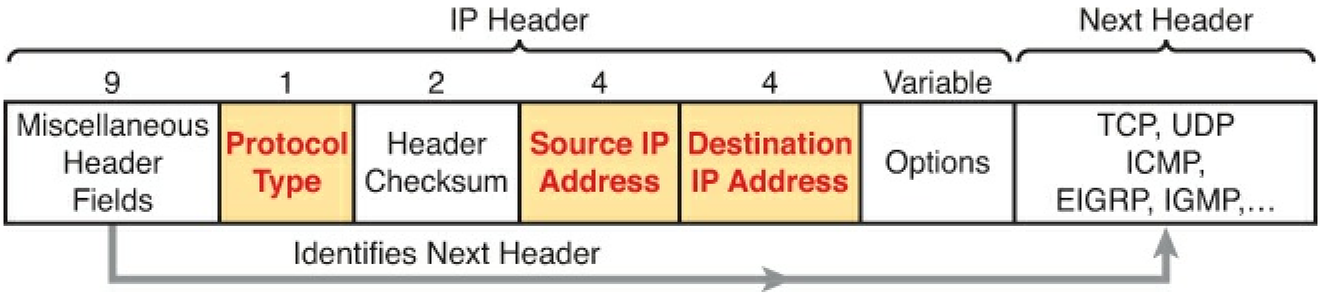


Figure 23-2. IP Header, with Focus on Required Fields in Extended IP ACLs

IOS requires that you configure parameters for the three highlighted parts of Figure 23-2. For the protocol type, you simply use a keyword, such as **tcp**, **udp**, or **icmp**, matching IP packets that happen to have a TCP, UDP, or ICMP header, respectively, following the IP header. Or you can use the keyword **ip**, which means "all ip packets." You also must configure some values for the source and destination IP address fields which follow; these fields use the same syntax and options for matching the IP addresses as discussed in Chapter 22, "Basic IPv4 Access Control Lists." Figure 23-3 shows the syntax.

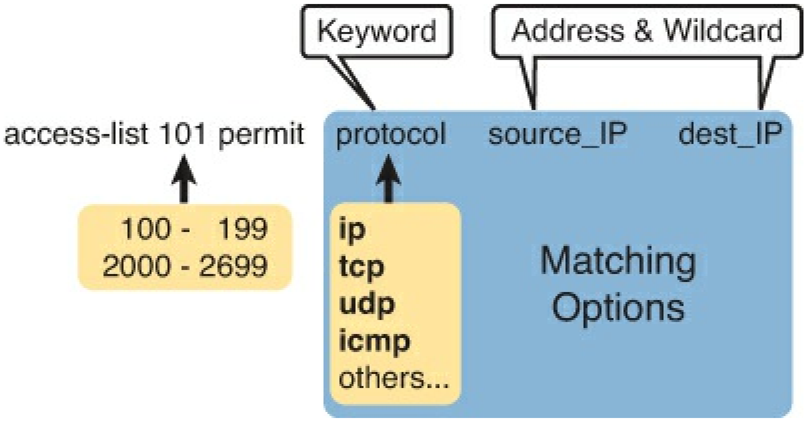
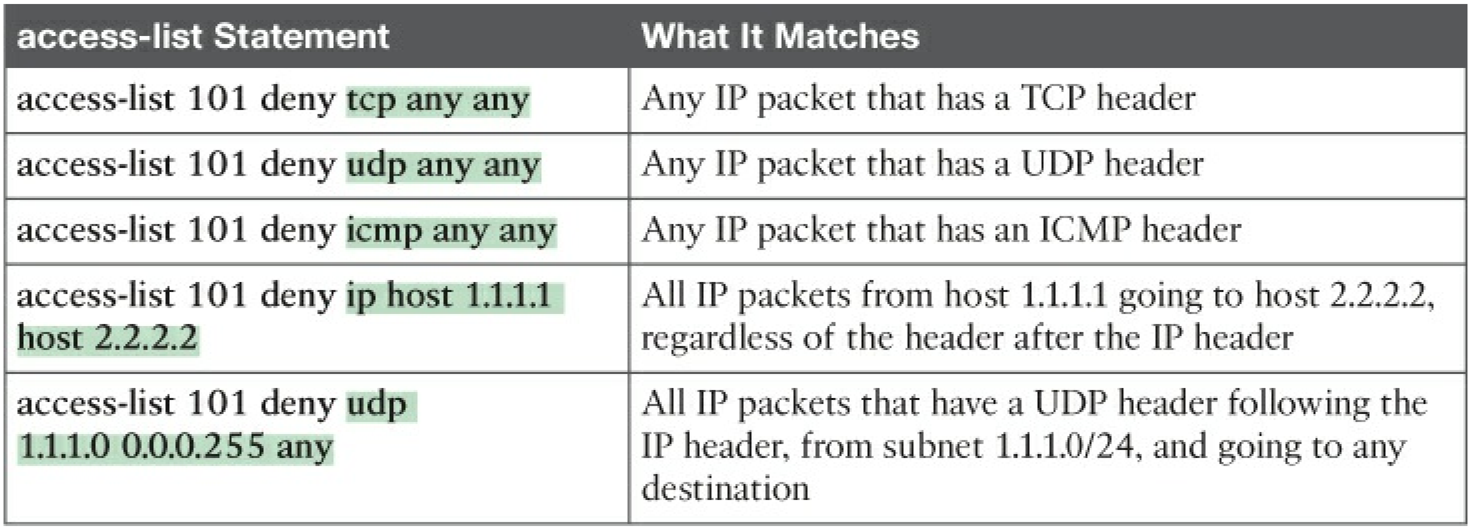


Figure 23-3. Extended ACL Syntax, with Required Fields

> **Note**
>
> When matching IP addresses in the source and destination fields, there is one difference with standard ACLs: When matching a specific IP address, the extended ACL requires the use of the **host** keyword. You cannot simply list the IP address alone.

Table 23-2 lists several sample **access-list** commands that use only the required matching parameters. Feel free to cover the right side and use the table for an exercise, or just review the explanations to get an idea for the logic in some sample commands.

Table 23-2. Extended access-list **Commands and Logic Explanations**



access-list Statement	What It Matches
access-list 101 deny tcp any any	Any IP packet that has a TCP header
access-list 101 deny udp any any	Any IP packet that has a UDP header
access-list 101 deny icmp any any	Any IP packet that has an ICMP header
access-list 101 deny ip host 1.1.1.1 host 2.2.2.2	All IP packets from host 1.1.1.1 going to host 2.2.2.2, regardless of the header after the IP header
access-list 101 deny udp 1.1.1.0 0.0.0.255 any	All IP packets that have a UDP header following the IP header, from subnet 1.1.1.0/24, and going to any destination

The last entry in Table 23-2 helps make an important point about how IOS processes extended ACLs:

Key Topic

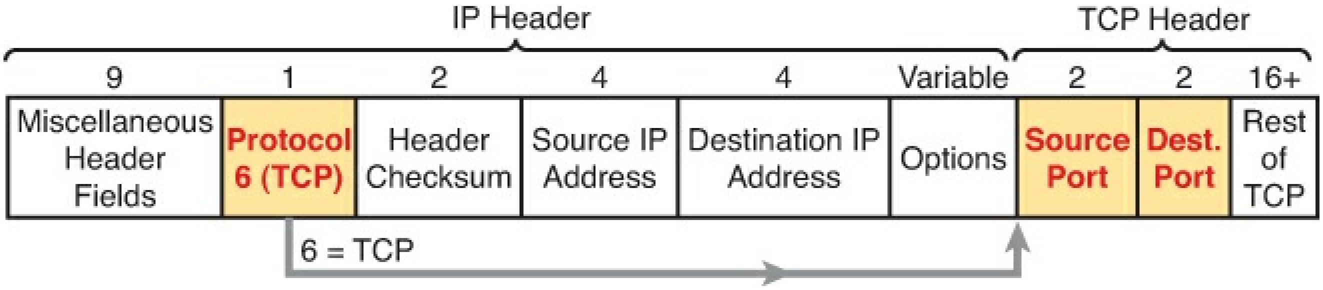
> In an extended ACL **access-list** command, all the matching parameters must match the packet for the packet to match the command.

For example, in that last example from Table 23-2, the command checks for UDP, a source IP address from subnet 1.1.1.0/24, and any destination IP address. If a packet with source IP address 1.1.1.1 were examined, it would match the source IP address check, but if it had a TCP header instead of UDP, it would not match this **access-list** command. All parameters must match.

Matching TCP and UDP Port Numbers

Extended ACLs can also examine parts of the TCP and UDP headers, particularly the source and destination port number fields. The port numbers identify the application that sends or receives the data.

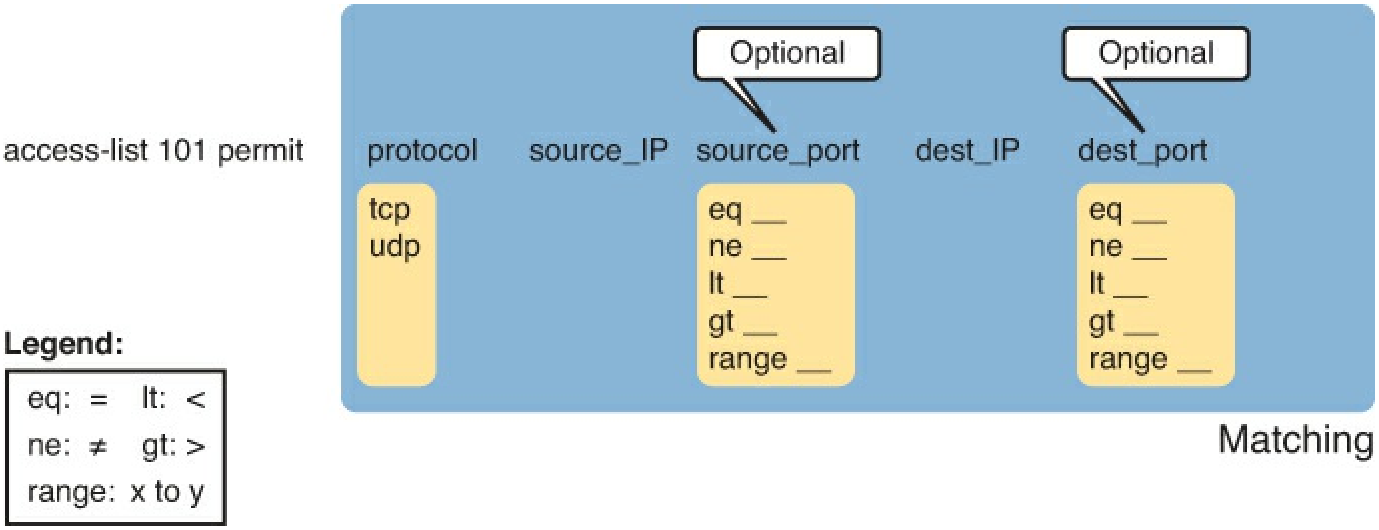
The most useful ports to check are the well-known ports used by servers. For example, web servers use well-known port 80 by default. Figure 23-4 shows the location of the port numbers in the TCP header, following the IP header.



IP Header
TCP Header
9
1
2
4
4
Variable
2
2
16+
Miscellaneous Header Fields
Protocol 6 (TCP)
Header Checksum
Source IP Address
Destination IP Address
Options
Source Port
Dest. Port
Rest of TCP
6 = TCP

Figure 23-4. IP Header, Followed by a TCP Header and Port Number Fields

When an extended ACL command includes either the **tcp** or **udp** keyword, that command can optionally reference the source and/or destination port. To make these comparisons, the syntax uses keywords for equal, not equal, less than, greater than, and for a range of port numbers. Additionally, the command can use either the literal decimal port numbers, or more convenient keywords for some well-known application ports. Figure 23-5 shows the positions of the source and destination port fields in the **access-list** command and these port number keywords.

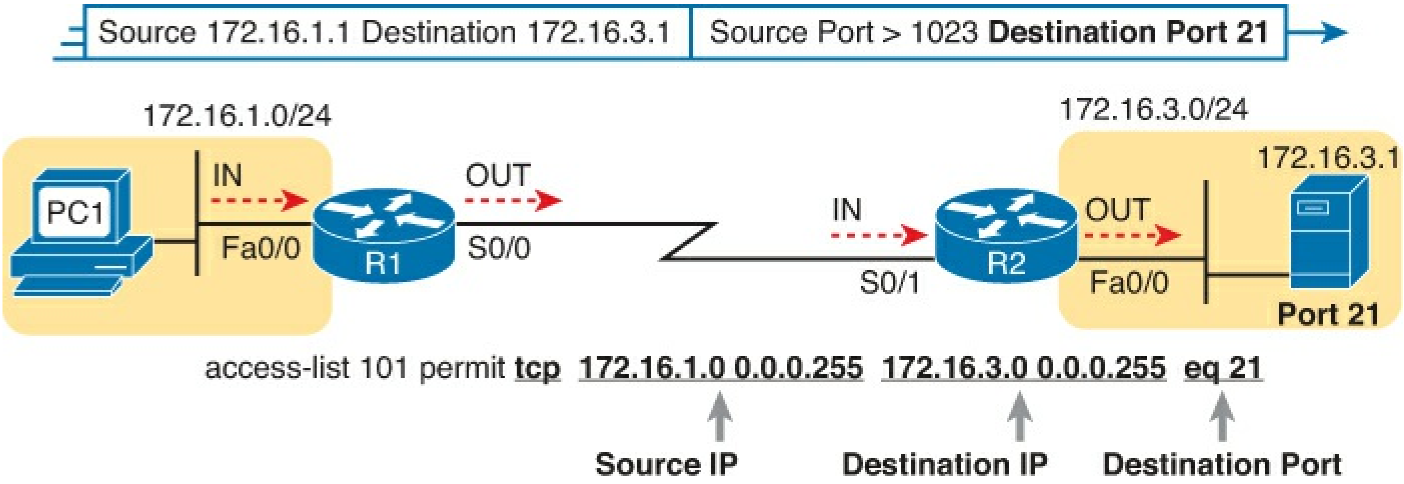


Optional
Optional
access-list 101 permit
protocol
source_IP
source_port
dest_IP
dest_port
tcp
udp
eq __
ne __
lt __
gt __
range __
eq __
ne __
lt __
gt __
range __
Matching
Legend:
eq: =
lt: <
ne: ≠
gt: >
range: x to y

Figure 23-5. Extended ACL Syntax with Port Numbers Enabled Using Protocol TCP or UDP

For example, consider the simple network shown in Figure 23-6. The FTP server sits on the right, with the client on the left. The figure shows the syntax of an ACL that matches the following:

- Packets that include a TCP header
- Packets sent from the client subnet
- Packets sent to the server subnet
- Packets with TCP destination port 21 (FTP server control port)



Source 172.16.1.1 Destination 172.16.3.1
Source Port > 1023 Destination Port 21
172.16.1.0/24
172.16.3.0/24
172.16.3.1
PC1
IN
Fa0/0
R1
OUT
S0/0
IN
S0/1
R2
OUT
Fa0/0
Port 21
access-list 101 permit tcp 172.16.1.0 0.0.0.255 172.16.3.0 0.0.0.255 eq 21
Source IP
Destination IP
Destination Port

Figure 23-6. Filtering Packets Based on Destination Port

To fully appreciate the matching of the destination port with the **eq 21** parameters, consider packets moving from left to right, from PC1 to the server. Assuming the server uses well-known port 21 (FTP control port), the packet's TCP header has a destination port value of 21. The ACL syntax includes the **eq 21** parameters after the destination IP address. The position after the destination address parameters is important: That position identifies the fact that the **eq 21** parameters should be compared to the packet's destination port. As a result, the ACL statement shown in Figure 23-6 would match this packet, and the destination port of 21, if used in any of the four locations implied by the four dashed arrowed lines in the figure.

Conversely, Figure 23-7 shows the reverse flow, with a packet sent by the server back toward PC1. In this case, the packet's TCP header has a source port of 21, so the ACL must check the source port value of 21, and the ACL must be located on different interfaces. In this case, the **eq 21** parameters follow the source address field, but comes before the destination address field.

Key Topic

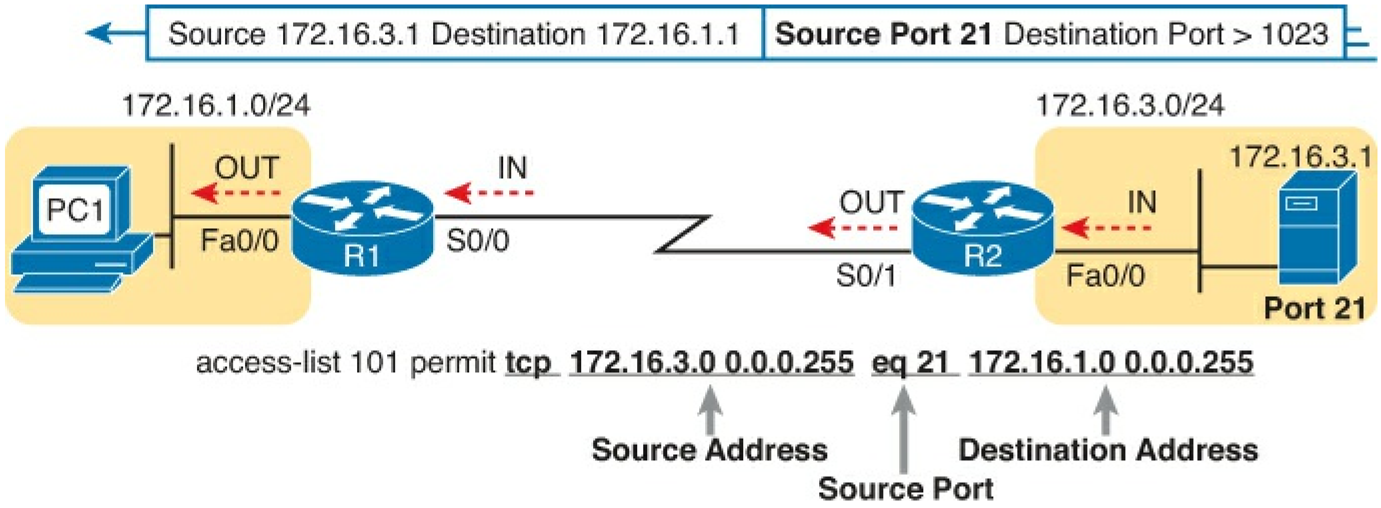
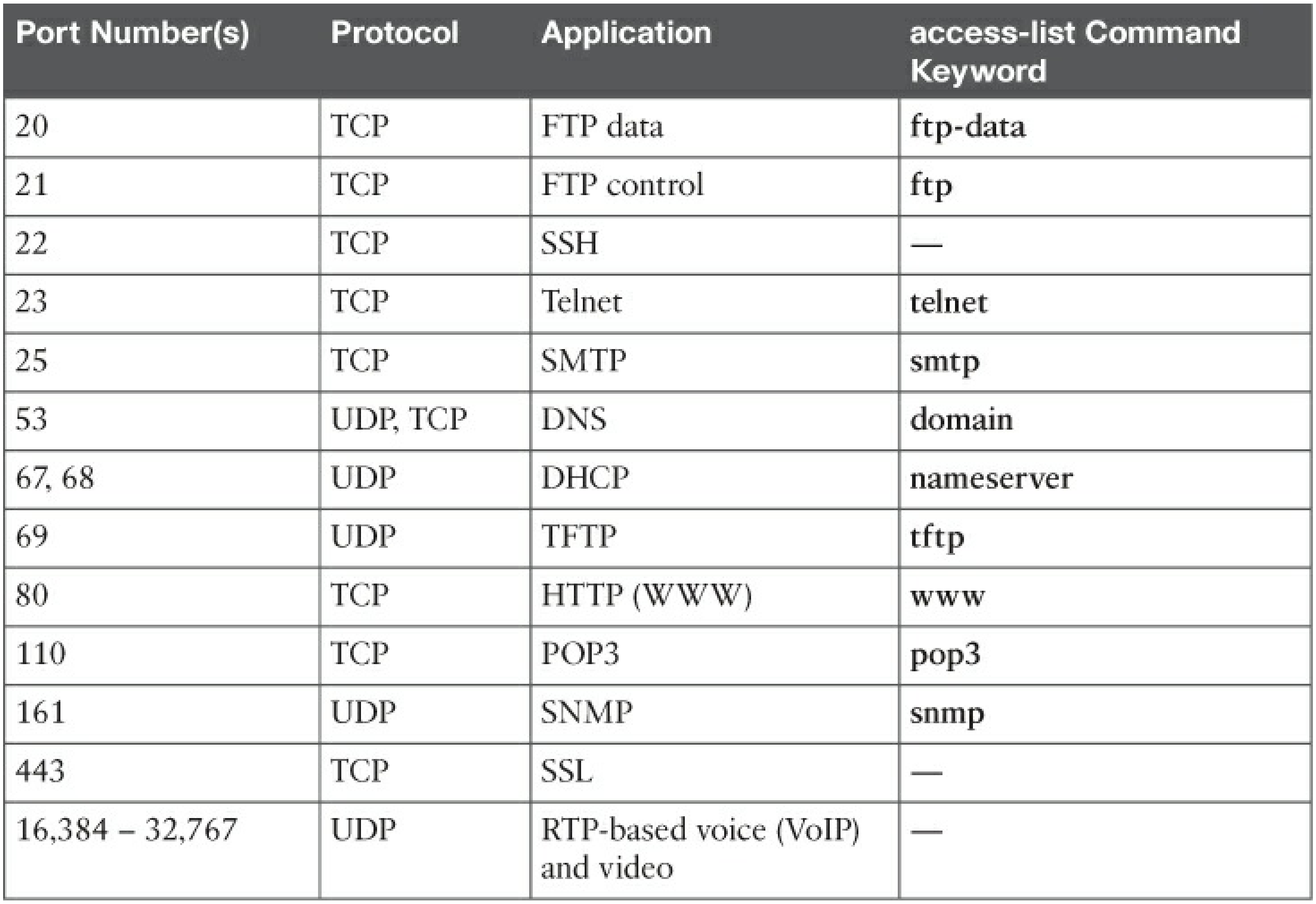

Source 172.16.3.1 Destination 172.16.1.1
Source Port 21 Destination Port > 1023
172.16.1.0/24
172.16.3.0/24
PC1
OUT
Fa0/0
R1
IN
S0/0
OUT
S0/1
R2
IN
Fa0/0
172.16.3.1
Port 21
access-list 101 permit tcp 172.16.3.0 0.0.0.255 eq 21 172.16.1.0 0.0.0.255
Source Address
Source Port
Destination Address

Figure 23-7. Filtering Packets Based on Source Port

For exam questions that require ACLs and matching of port numbers, first consider the location and direction in which the ACL will be applied. That direction determines whether the packet is being sent to the server, or from the server. At that point, you can decide whether you need to check the source or destination port in the packet, assuming you want to check the well-known port used by that service.

For reference, Table 23-3 lists many of the popular port numbers and their transport layer protocols and applications. Note that the syntax of the **access-list** commands accepts both the port numbers and a shorthand version of the application name.

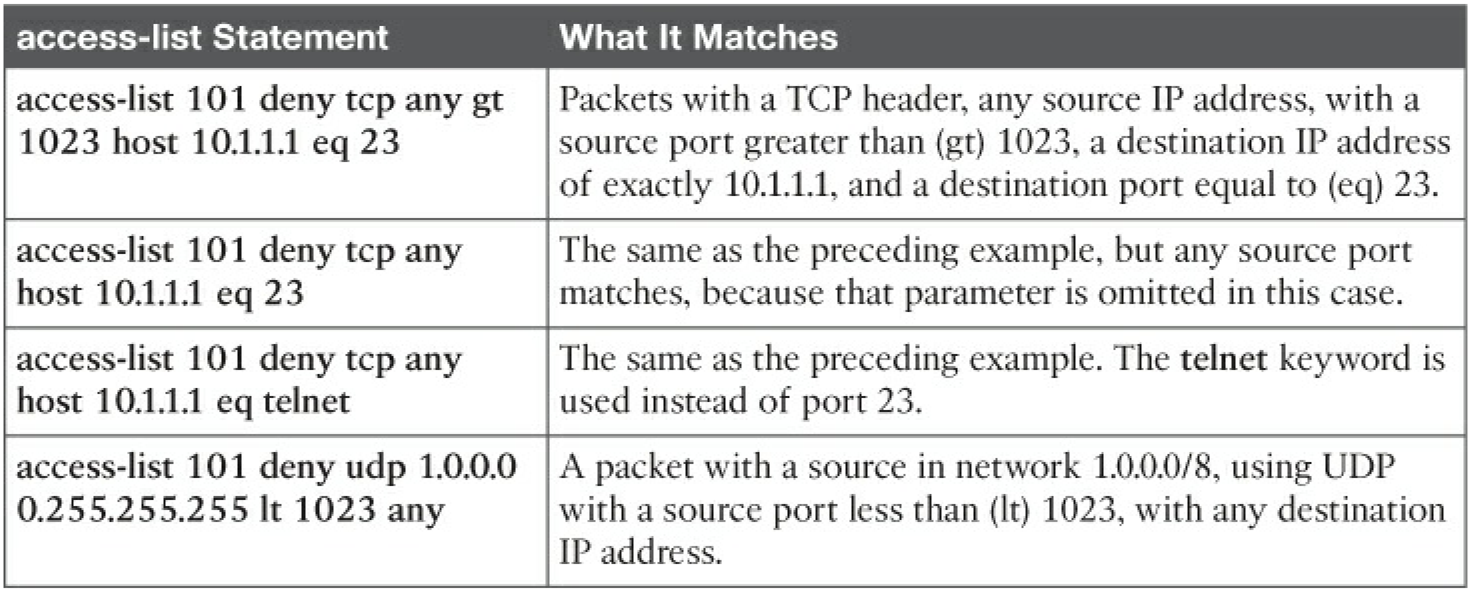
Table 23-3. Popular Applications and Their Well-Known Port Numbers



Port Number(s)	Protocol	Application	access-list Command Keyword
20	TCP	FTP data	**ftp-data**
21	TCP	FTP control	**ftp**
22	TCP	SSH	—
23	TCP	Telnet	**telnet**
25	TCP	SMTP	**smtp**
53	UDP, TCP	DNS	**domain**
67, 68	UDP	DHCP	**nameserver**
69	UDP	TFTP	**tftp**
80	TCP	HTTP (WWW)	**www**
110	TCP	POP3	**pop3**
161	UDP	SNMP	**snmp**
443	TCP	SSL	—
16,384 – 32,767	UDP	RTP-based voice (VoIP) and video	—

Table 23-4 lists several example **access-list** commands that match based on port numbers. Cover the right side of the table, and try to characterize the packets matched by each command. Then, check the right side of the table to see if you agree with the assessment.

Table 23-4. Example Extended access-list **Commands and Logic Explanations**

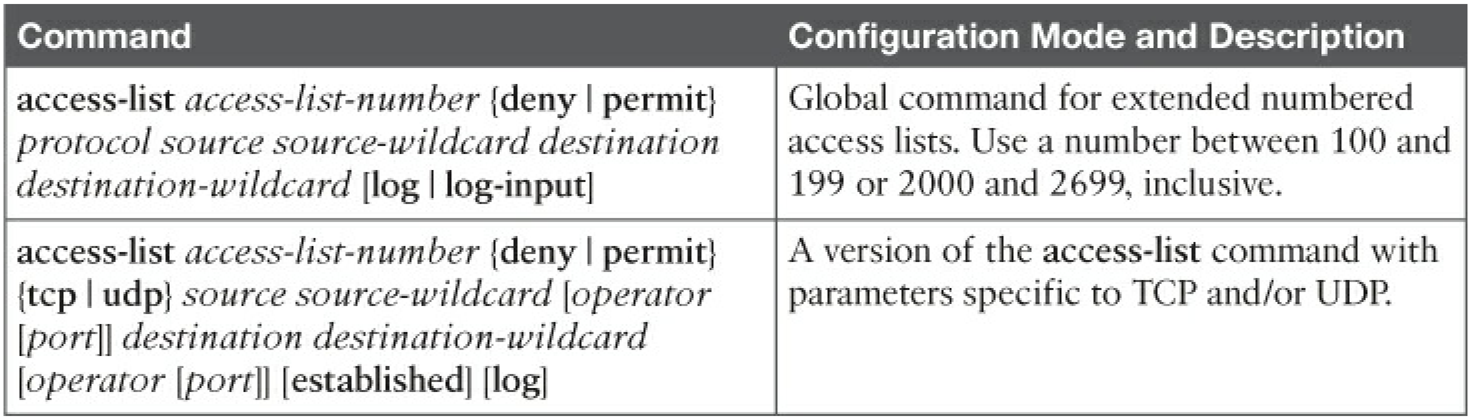


access-list Statement	What It Matches
access-list 101 deny tcp any gt 1023 host 10.1.1.1 eq 23	Packets with a TCP header, any source IP address, with a source port greater than (gt) 1023, a destination IP address of exactly 10.1.1.1, and a destination port equal to (eq) 23.
access-list 101 deny tcp any host 10.1.1.1 eq 23	The same as the preceding example, but any source port matches, because that parameter is omitted in this case.
access-list 101 deny tcp any host 10.1.1.1 eq telnet	The same as the preceding example. The **telnet** keyword is used instead of port 23.
access-list 101 deny udp 1.0.0.0 0.255.255.255 lt 1023 any	A packet with a source in network 1.0.0.0/8, using UDP with a source port less than (lt) 1023, with any destination IP address.

Extended IP ACL Configuration

Because extended ACLs can match so many different fields in the various headers in an IP packet, the command syntax cannot be easily summarized in a single generic command. However, for CCNA preparation, you can rely mainly on two references for syntax, as listed in Table 23-5.

Table 23-5. Extended IP Access List Configuration Commands



Command	Configuration Mode and Description
access-list *access-list-number* {**deny** | **permit**} *protocol source source-wildcard destination destination-wildcard* [**log** | **log-input**]	Global command for extended numbered access lists. Use a number between 100 and 199 or 2000 and 2699, inclusive.
access-list *access-list-number* {**deny** | **permit**} {**tcp** | **udp**} *source source-wildcard* [*operator* [*port*]] *destination destination-wildcard* [*operator* [*port*]] [**established**] [**log**]	A version of the **access-list** command with parameters specific to TCP and/or UDP.

The configuration process for extended ACLs mostly matches the same process used for standard ACLs. You must choose the location and direction in which to enable the ACL, particularly the direction, so that you can characterize whether certain addresses and ports will be either the source or destination. Configure the ACL using **access-list** commands, and when complete, then enable the ACL using the same **ip access-group** command used with standard ACLs. All these steps mirror what you do with standard ACLs; however, when configuring, keep the following differences in mind:

Key Topic

- Place extended ACLs as close as possible to the source of the packets that will be filtered. Filtering close to the source of the packets saves some bandwidth.
- Remember that all fields in one **access-list** command must match a packet for the packet to be considered to match that **access-list** statement.
- Use numbers of 100–199 and 2000–2699 on the **access-list** commands; no one number is inherently better than another.

Extended IP Access Lists: Example 1

This example focuses on understanding basic syntax. In this case, the ACL denies Bob access to all FTP servers on R1's Ethernet, and it denies Larry access to Server1's web server. Figure 23-8 shows the network topology; Example 23-1 shows the configuration on R1.

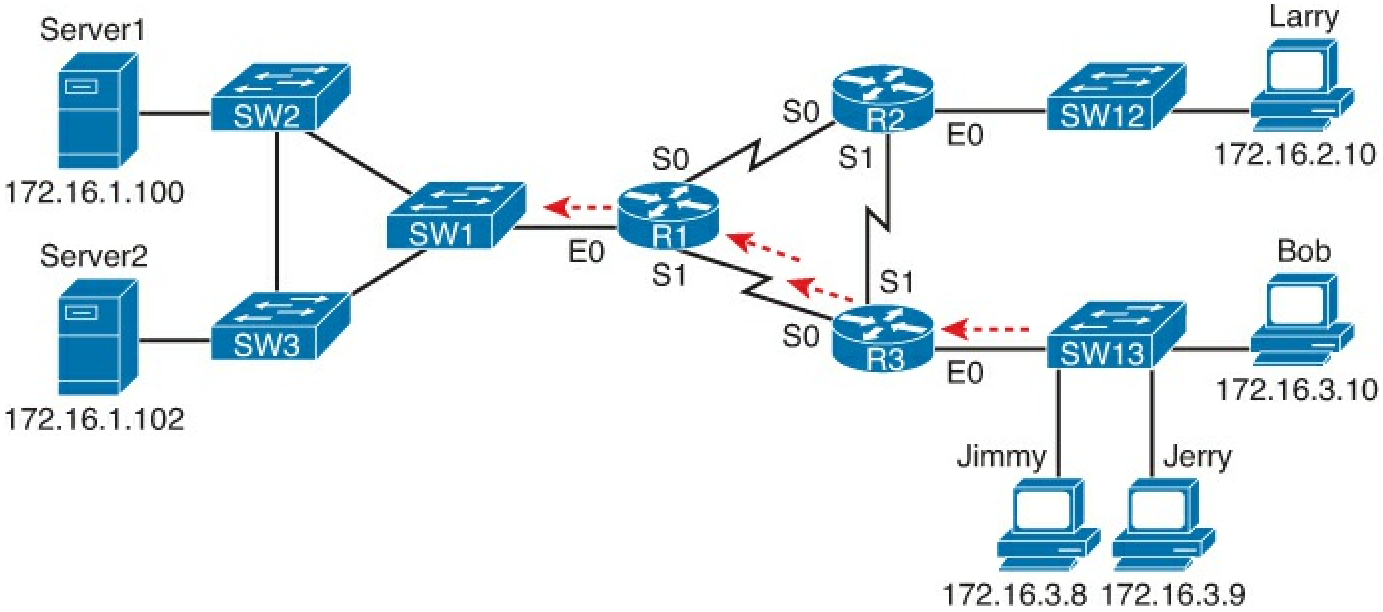


Figure 23-8. Network Diagram for Extended Access List Example 1

Example 23-1. R1's Extended Access List: Example 1

Click here to view code image

```
interface Serial0
ip address 172.16.12.1 255.255.255.0
ip access-group 101 in
!
interface Serial1
```

```
ip address 172.16.13.1 255.255.255.0
ip access-group 101 in
!
access-list 101 remark Stop Bob to FTP servers, and Larry to Server1 web
access-list 101 deny tcp host 172.16.3.10 172.16.1.0 0.0.0.255 eq ftp
access-list 101 deny tcp host 172.16.2.10 host 172.16.1.100 eq www
access-list 101 permit ip any any
```

The first ACL statement prevents Bob's access to FTP servers in subnet 172.16.1.0. The second statement prevents Larry's access to web services on Server1. The final statement permits all other traffic.

Focusing on the syntax for a moment, there are several new items to review. First, the access-list number for extended access lists falls in the range of 100–199 or 2000–2699. Following the **permit** or **deny** action, the *protocol* parameter defines whether you want to check for all IP packets or specific headers, such as TCP or UDP headers. When you check for TCP or UDP port numbers, you must specify the TCP or UDP protocol. Both FTP and web use TCP.

This example uses the **eq** parameter, meaning "equals," to check the destination port numbers for FTP control (keyword **ftp**) and HTTP traffic (keyword **www**). You can use the numeric values—or, for the more popular options, a more obvious text version is valid. (If you were to type **eq 80**, the config would show **eq www**.)

This example enables the ACL in two places on R1: inbound on each serial interface. These locations achieve the goal of the ACL. However, that initial placement was made to make the point that Cisco suggests that you locate them as close as possible to the source of the packet. Therefore, Example 23-2 achieves the same goal as Example 23-1 of stopping Bob's access to FTP servers at the main site, and it does so with an ACL on R3.

Example 23-2. R3's Extended Access List Stopping Bob from Reaching FTP Servers Near R1

Click here to view code image

```
interface Ethernet0
ip address 172.16.3.1 255.255.255.0
ip access-group 103 in

access-list 103 remark deny Bob to FTP servers in subnet 172.16.1.0/24
access-list 103 deny tcp host 172.16.3.10 172.16.1.0 0.0.0.255 eq ftp
access-list 103 permit ip any any
```

The new configuration on R3 meets the goals to filter Bob's traffic, while also meeting the overarching design goal of keeping the ACL close to the source of the packets. ACL 103 on R3 looks a lot like ACL 101 on R1 from Example 23-1, but this time, the ACL does not bother to check for the criteria to match Larry's traffic, because Larry's traffic will never enter R3's Ethernet 0 interface. ACL 103 filters Bob's FTP traffic to destinations in subnet 172.16.1.0/24, with all other traffic entering R3's E0 interface making it into the network.

Extended IP Access Lists: Example 2

Example 23-3, based on the network shown in Figure 23-9, shows another example of how to use extended IP access lists. This example uses the following criteria:

- Sam is not allowed access to the subnet of Bugs or Daffy.
- Hosts on the Seville Ethernet are not allowed access to hosts on the Yosemite Ethernet.
- All other combinations are allowed.

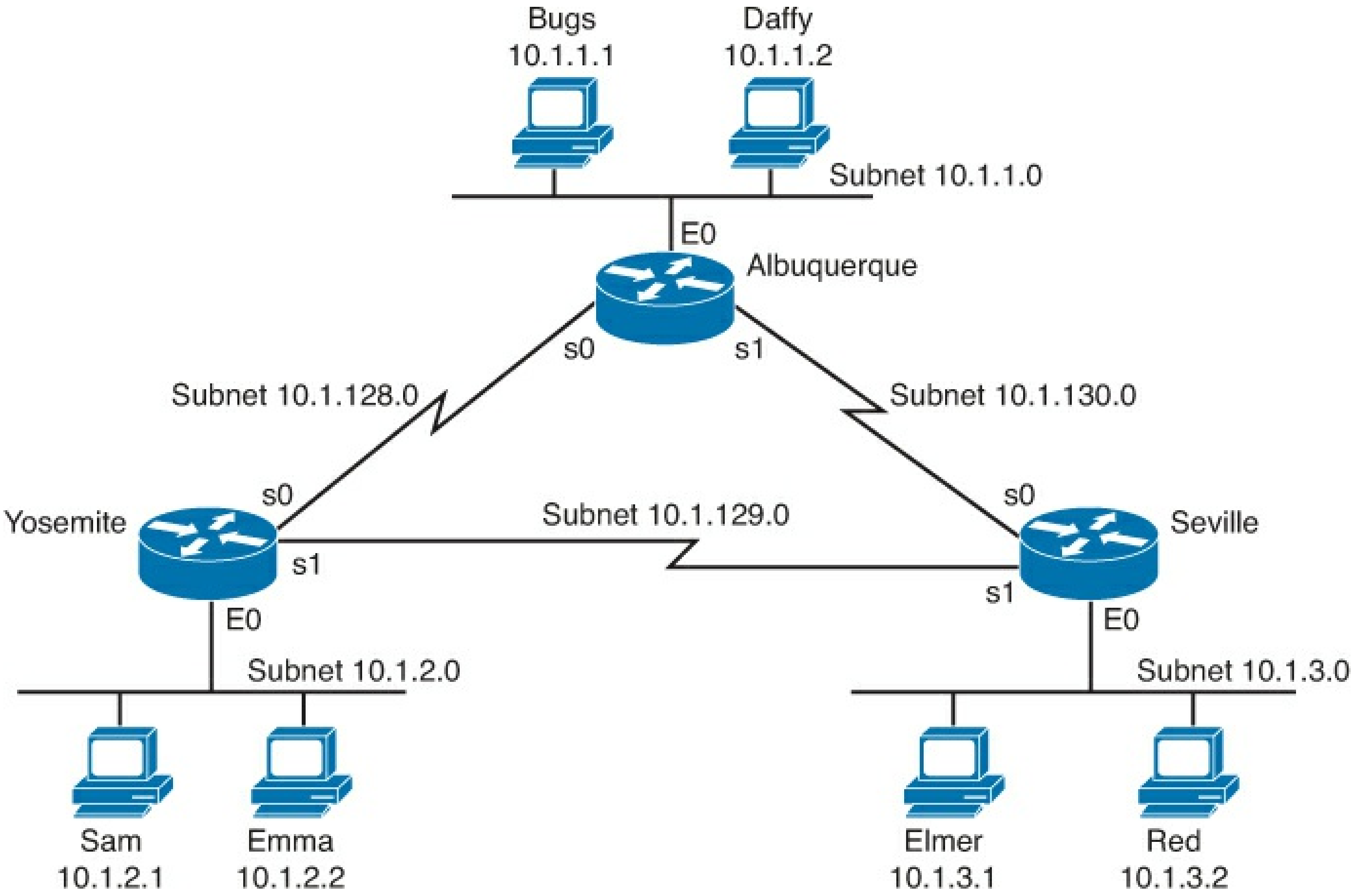

Bugs
10.1.1.1
Daffy
10.1.1.2
Subnet 10.1.1.0
E0
Albuquerque
s0
s1
Subnet 10.1.128.0
Subnet 10.1.130.0
s0
Yosemite
Subnet 10.1.129.0
s0
Seville
s1
s1
E0
E0
Subnet 10.1.2.0
Subnet 10.1.3.0
Sam
10.1.2.1
Emma
10.1.2.2
Elmer
10.1.3.1
Red
10.1.3.2

Figure 23-9. Network Diagram for Extended Access List Example 2

Example 23-3. Yosemite Configuration for Extended Access List Example

Click here to view code image

```
interface ethernet 0
ip access-group 110 in
!
access-list 110 deny ip host 10.1.2.1 10.1.1.0 0.0.0.255
access-list 110 deny ip 10.1.2.0 0.0.0.255 10.1.3.0 0.0.0.255
access-list 110 permit ip any any
```

This configuration solves the problem with few statements while keeping to the Cisco design guideline of placing extended ACLs as close as possible to the source of the traffic. The ACL filters packets that enter Yosemite's E0 interface, which is the first router interface that packets sent by Sam enter. If the route between Yosemite and the other subnets changes over time, the ACL still applies. Also, the filtering mandated by the second requirement (to disallow Seville's LAN hosts from accessing Yosemite's) is met by the second **access-list** statement. Stopping packet flow from Yosemite's LAN subnet to Seville's LAN subnet stops effective communication between the two subnets. Alternatively, the opposite logic could have been configured at Seville.

Practice Building access-list Commands

Table 23-6 supplies a practice exercise to help you get comfortable with the syntax of the extended **access-list** command, particularly with choosing the correct matching logic. Your job: create a one-line extended ACL that matches the packets. The answers are in the section, "Answers to Earlier Practice Problems," later in this chapter. Note that if the criteria mentions a particular application protocol, for example, "web client," that means to specifically match for that application protocol.

Table 23-6. Building One-Line Extended ACLs: Practice

Problem	Criteria
1	From web client 10.1.1.1, sent to a web server in subnet 10.1.2.0/24.
2	From telnet client 172.16.4.3/25, sent to a Telnet server in subnet 172.16.3.0/25. Match all hosts in the client's subnet as well.
3	ICMP messages from the subnet in which 192.168.7.200/26 resides to all hosts in the subnet where 192.168.7.14/29 resides.
4	From web server 10.2.3.4/23's subnet to clients in the same subnet as host 10.4.5.6/22.
5	From telnet server 172.20.1.0/24's subnet to clients in the same subnet as host 172.20.44.1/23.
6	From web client 192.168.99.99/28, sent to a web server in subnet 192.168.176.0/28. Match all hosts in the client's subnet as well.
7	ICMP messages from the subnet in which 10.55.66.77/25 resides to all hosts in the subnet where 10.66.55.44/26 resides.
8	Any and every IPv4 packet.

Named ACLs and ACL Editing

Now that you have a good understanding of the core concepts in IOS IP ACLs, this section examines a few enhancements to IOS support for ACLs: named ACLs and ACL editing with sequence numbers. Although both features are useful and important, neither adds any function as to what a router can and cannot filter. Instead, named ACLs and ACL sequence numbers make it easier to remember ACL names and edit existing ACLs when an ACL needs to change.

Named IP Access Lists

Named IP ACLs have many similarities with numbered IP ACLs. They can be used for filtering packets, plus for many other purposes. And just like there are both standard and extended numbered ACLs that differ in regards to what packets each can match, there are also standard and extended named ACLs.

Named ACLs originally had three big differences compared to numbered ACLs:

Key Topic

- Using names instead of numbers to identify the ACL, making it easier to remember the reason for the ACL
- Using ACL subcommands, not global commands, to define the action and matching parameters
- ACL editing features that allow the CLI user to delete individual lines from the ACL and insert new lines

You can easily learn named ACL configuration by just converting numbered ACLs to use the equivalent named ACL configuration. Figure 23-10 shows just such a conversion, using a simple three-line standard ACL number 1. To create the three **permit** subcommands for the named ACL, you literally copy parts of the three numbered ACL commands, beginning with the **permit** keyword.

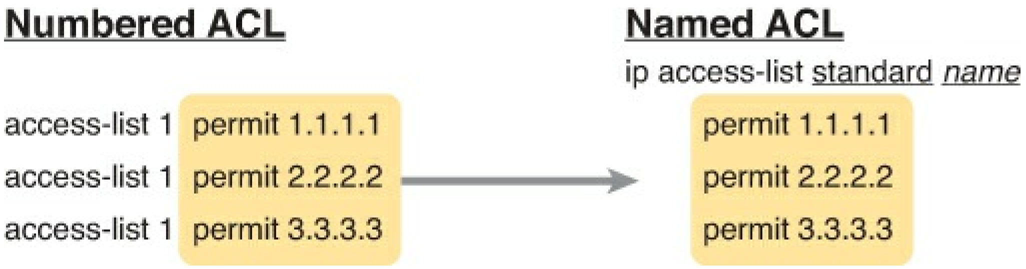


Figure 23-10. Named ACL Versus Numbered ACL Configuration

The only truly new part of the named ACL configuration is the **ip access-list** global configuration command. This command defines whether an ACL is a standard or extended ACL, and defines the name. It also moves the user to ACL configuration mode, as seen in upcoming Example 23-4. Once in ACL configuration mode, you configure **permit**, **deny**, and **remark** commands that mirror the syntax of numbered ACL **access-list** commands. If configuring a standard named ACL, these commands match the syntax of standard numbered ACLs; if configuring extended named ACLs, they match the syntax of extended numbered ACLs.

Example 23-4 shows the configuration of a named extended ACL. Pay particular attention to the configuration mode prompts, which shows ACL configuration mode.

Example 23-4. Named Access List Configuration

Click here to view code image

```
Router# configure terminal
Enter configuration commands, one per line. End with Ctrl-Z.
Router(config)# ip access-list extended barney
Router(config-ext-nacl)# permit tcp host 10.1.1.2 eq www any
Router(config-ext-nacl)# deny udp host 10.1.1.1 10.1.2.0 0.0.0.255
Router(config-ext-nacl)# deny ip 10.1.3.0 0.0.0.255 10.1.2.0 0.0.0.255
Router(config-ext-nacl)# deny ip 10.1.2.0 0.0.0.255 10.2.3.0 0.0.0.255
Router(config-ext-nacl)# permit ip any any
Router(config-ext-nacl)# interface serial1
Router(config-if)# ip access-group barney out
Router(config-if)# ^Z
Router# show running-config
Building configuration...

Current configuration:

! lines omitted for brevity

interface serial 1
ip access-group barney out
!
ip access-list extended barney
permit tcp host 10.1.1.2 eq www any
deny udp host 10.1.1.1 10.1.2.0 0.0.0.255
deny ip 10.1.3.0 0.0.0.255 10.1.2.0 0.0.0.255
deny ip 10.1.2.0 0.0.0.255 10.2.3.0 0.0.0.255
permit ip any any
```

Example 23-4 begins with the creation of an ACL named barney. The **ip access-list extended barney** command creates the ACL, naming it barney and placing the user in ACL configuration mode. This command also tells the IOS that barney is an extended ACL. Next, five different **permit** and **deny** statements define the matching logic and action to be taken upon a match. The **show running-config** command output lists the named ACL configuration before the single entry is deleted.

Named ACLs allow the user to delete and add new lines to the ACL from within ACL configuration mode. Example 23-5 shows how, with the **no deny ip . . .** command deleting a single entry from the ACL. Notice that the output of the **show access-list** command at the end of the example still lists the ACL, with four **permit** and **deny** commands instead of five.

Example 23-5. Removing One Command from a Named ACL

Click here to view code image

```
Router# configure terminal
Enter configuration commands, one per line. End with Ctrl-Z.
Router(config)# ip access-list extended barney
Router(config-ext-nacl)# no deny ip 10.1.2.0 0.0.0.255 10.2.3.0 0.0.0.255
Router(config-ext-nacl)# ^Z
Router# show access-list

Extended IP access list barney
10 permit tcp host 10.1.1.2 eq www any
20 deny udp host 10.1.1.1 10.1.2.0 0.0.0.255
30 deny ip 10.1.3.0 0.0.0.255 10.1.2.0 0.0.0.255
50 permit ip any any
```

Editing ACLs Using Sequence Numbers

Numbered ACLs have existed in IOS since the early days of Cisco routers and IOS. However, for many years, through many IOS versions, the ability to edit a numbered IP ACL was poor. For example, to simply delete a line from the ACL, the user had to delete the entire ACL and then reconfigure it.

Today, modern IOS versions allow CLI users to easily edit both numbered and named ACLs. Cisco first introduced these enhanced ACL editing features in named ACLs only, and slowly added them to numbered ACLs as well. This section examines these great ACL editing features that have been around in IOS since Version 12.3, which as of the writing of this book, is now a relatively old IOS version.

The ACL editing feature uses an ACL sequence number that is added to each ACL **permit** or **deny** statement, with the numbers representing the sequence of statements in the ACL. ACL sequence numbers provide the following features for both numbered and named ACLs:

Key Topic

New Configuration Style for Numbered: Numbered ACLs use a configuration style like named ACLs, as well as the traditional style, for the same ACL; the new style is required to perform advanced ACL editing.

Deleting Single Lines: An individual ACL **permit** or **deny** statement can be deleted with a **no** *sequence-number* subcommand.

Inserting New Lines: Newly added **permit** and **deny** commands can be configured with a sequence number, dictating the location of the statement within the ACL.

Automatic Sequence Numbering: IOS adds sequence numbers to commands as you configure them, even if you do not include the sequence numbers.

To take advantage of the ability to delete and insert lines in an ACL, both numbered and named ACLs must use the same overall configuration style and commands used for named ACLs. The only difference in syntax is whether a name or number is used. Example 23-6 shows the configuration of a standard numbered IP ACL, using this alternative configuration style. The example shows the power of the ACL sequence number for editing. In this example, the following occurs:

Step 1. Numbered ACL 24 is configured using this new-style configuration, with three **permit** commands.

Step 2. The **show ip access-list** command shows the three permit commands with sequence numbers 10, 20, and 30.

Step 3. The engineer deletes only the second **permit** command using the **no 20** ACL subcommand, which simply refers to sequence number 20.

Step 4. The **show ip access-list** command confirms that the ACL now has only two lines (sequence numbers 10 and 30).

Step 5. The engineer adds a new **deny** command to the beginning of the ACL, using the **5 deny 10.1.1.1** ACL subcommand.

Step 6. The **show ip access-list** command again confirms the changes, this time listing three **permit** commands, sequence numbers 5, 10, and 30.

> **Note**
>
> For this example, note that the user does not leave configuration mode, instead using the **do** command to tell IOS to issue the **show ip access-list** EXEC command from configuration mode.

Example 23-6. Editing ACLs Using Sequence Numbers

Click here to view code image

```
! Step 1: The 3-line Standard Numbered IP ACL is configured.
R1# configure terminal
Enter configuration commands, one per line. End with Ctrl-Z.
R1(config)# ip access-list standard 24
R1(config-std-nacl)# permit 10.1.1.0 0.0.0.255
R1(config-std-nacl)# permit 10.1.2.0 0.0.0.255
R1(config-std-nacl)# permit 10.1.3.0 0.0.0.255

! Step 2: Displaying the ACL's contents, without leaving configuration mode.
R1(config-std-nacl)# do show ip access-list 24
Standard IP access list 24
10 permit 10.1.1.0, wildcard bits 0.0.0.255
20 permit 10.1.2.0, wildcard bits 0.0.0.255
30 permit 10.1.3.0, wildcard bits 0.0.0.255

! Step 3: Still in ACL 24 configuration mode, the line with sequence number 20 is deleted.
R1(config-std-nacl)# no 20

! Step 4: Displaying the ACL's contents again, without leaving configuration mode.
! Note that line number 20 is no longer listed.
```

```
R1(config-std-nacl)#do show ip access-list 24
Standard IP access list 24
10 permit 10.1.1.0, wildcard bits 0.0.0.255
30 permit 10.1.3.0, wildcard bits 0.0.0.255

! Step 5: Inserting a new first line in the ACL.
R1(config-std-nacl)# 5 deny 10.1.1.1

! Step 6: Displaying the ACL's contents one last time, with the new statement !(sequence number 5) listed first.
R1(config-std-nacl)# do show ip access-list 24
Standard IP access list 24
5 deny 10.1.1.1
10 permit 10.1.1.0, wildcard bits 0.0.0.255
30 permit 10.1.3.0, wildcard bits 0.0.0.255
```

Note that while Example 23-6 uses a numbered ACL, named ACLs use the same process to edit (add and remove) entries.

Numbered ACL Configuration Versus Named ACL Configuration

As a brief aside about numbered ACLs, note that IOS actually allows two ways to configure numbered ACLs in the more recent versions of IOS. First, IOS supports the traditional method, using the **access-list** global commands seen earlier in Examples 23-1, 23-2, and 23-3. IOS also supports the numbered ACL configuration with commands just like named ACLs, as seen in Example 23-6.

Oddly, IOS always stores numbered ACLs with the original style of configuration, as global **access-list** commands, no matter which method is used to configure the ACL. Example 23-7 demonstrates these facts, picking up where Example 23-6 ended, with the following additional steps:

Step 7. The engineer lists the configuration (**show running-config**), which lists the old-style configuration commands—even though the ACL was created with the new-style commands.

Step 8. The engineer adds a new statement to the end of the ACL using the old-style **access-list 24 permit 10.1.4.0 0.0.0.255** global configuration command.

Step 9. The **show ip access-list** command confirms that the old-style **access-list** command from the previous step followed the rule of being added only to the end of the ACL.

Step 10. The engineer displays the configuration to confirm that the parts of ACL 24 configured with both new-style commands and old-style commands are all listed in the same old-style ACL (**show running-config**).

Example 23-7. Adding to and Displaying a Numbered ACL Configuration

Click here to view code image

```
! Step 7: A configuration snippet for ACL 24.
R1# show running-config
! The only lines shown are the lines from ACL 24
access-list 24 deny 10.1.1.1
access-list 24 permit 10.1.1.0 0.0.0.255
access-list 24 permit 10.1.3.0 0.0.0.255

! Step 8: Adding a new access-list 24 global command
R1# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R1(config)# access-list 24 permit 10.1.4.0 0.0.0.255
R1(config)# ^Z

! Step 9: Displaying the ACL's contents again, with sequence numbers. Note that even
! the new statement has been automatically assigned a sequence number.
R1# show ip access-list 24
Standard IP access list 24
5 deny 10.1.1.1
10 permit 10.1.1.0, wildcard bits 0.0.0.255
30 permit 10.1.3.0, wildcard bits 0.0.0.255
40 permit 10.1.4.0, wildcard bits 0.0.0.255

! Step 10: The numbered ACL configuration remains in old-style configuration commands.
R1# show running-config
! The only lines shown are the lines from ACL 24
access-list 24 deny 10.1.1.1
```

```
access-list 24 permit 10.1.1.0 0.0.0.255
access-list 24 permit 10.1.3.0 0.0.0.255
access-list 24 permit 10.1.4.0 0.0.0.255
```

Router and Switch Security

This final section of the chapter looks at a variety of short topics, all with some tie to how to secure routers and switches. Some features use ACLs to better secure the router or switch, while other features simply define how to use some Cisco-recommended best practices for protecting the device.

Specifically, this section reviews password security, disabling unnecessary services, disabling Telnet, securing VTY (Telnet and SSH) access with ACLs, how to choose the best locations for ACLs, and Network Time Protocol (NTP).

Review: Password Protections for the CLI

Chapter 7, "Installing and Operating Cisco LAN Switches," and Chapter 8, "Configuring Ethernet Switching," discussed how routers and switches protect CLI access using different passwords. As a reminder, Figure 23-11 reviews the locations where IOS can require a password to get into the CLI, or move to a different mode: the console, vty, and to move from user to enable mode.

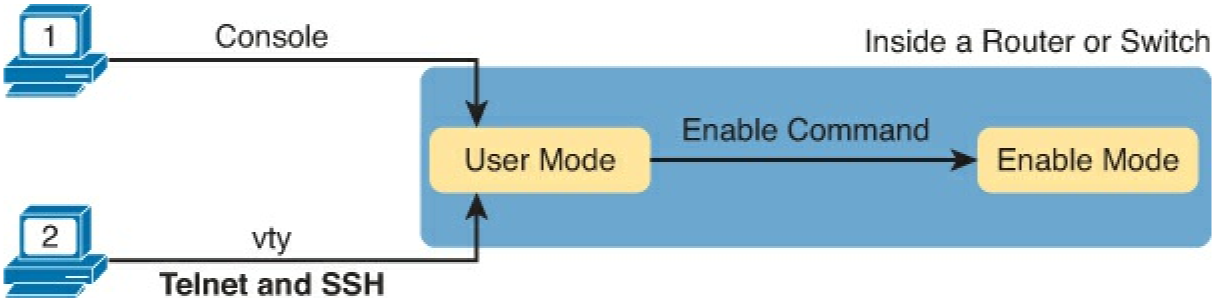


Figure 23-11. Locations to Consider Passwords: Console, vty, and Enable

The following list summarizes some recommendations for how to secure a router or switch CLI. Note that Chapter 8 explains the meaning of all these commands, with examples of several of these. The following list simply points out the reasons for using the various password options.

- Use the **enable secret** command, instead of the combination of the **enable password** command plus the **service password-encryption** command. Both result in what looks like a scrambled password when displayed with the **show running-config** command. However, the **enable secret** command uses stronger password encryption, while passwords encrypted with the **service password-encryption** command can be easily broken.
- Avoid using simple password checking for the console or VTYs with the **login** line-mode command, because this method does not identify individual users.
- Optimally, authenticate CLI logins using an external authentication server, like a RADIUS server. However, if necessary, use locally configured **username secret** commands, which hides the passwords with a hash (as does the **enable secret** command).
- Disable support for inbound Telnet connections, because Telnet sends the passwords as clear text, opening up the possibility of someone capturing the packets and stealing the password. Instead, configure the router and switch to allow SSH only, using the **transport input ssh** command in VTY line mode.

While all of these activities are important, all require that you also maintain solid physical security for your networking devices. The devices should be in a secured area, where only authorized personnel can physically reach the devices. Once an attacker gains physical access to a router or switch, they can remove cables, power off devices, and even reset passwords from the console, allowing them to access the devices remotely at a later time.

Disable Services

Cisco IOS, like any other OS, has to have some default settings. Those default settings include a variety of services that IOS supports for good reason. However, for most any service that a computer uses for good reason, hackers can use as a way to attack a network, or at least learn information that helps in some other attack. So, every good security plan looks at each OS used in a network, finds any default settings that can create a security exposure, and changes the default settings to minimize security risks.

Cisco makes several recommendations about what to disable and enable on IOS (for both routers and switches) as part of a good security plan. This section discusses a few such items, to give you an idea of the kinds of things to consider. However, this section does not attempt to list them all; the Cisco security certification track gets into more details about these features.

> **Note**
>
> For the curious: Go to Cisco.com and search for "Guide to Harden Cisco IOS Devices" for a more detailed document about recommendations for securing routers and switches.

Cisco IOS supports a graphical user interface (GUI) to do the same work as done at the CLI. To make that work, IOS acts as a web server. By default, IOS enables an HTTP web service that does not encrypt data (HTTP), with an option to configure an HTTP service that does encrypt data (HTTPS). The recommendation? Disable the HTTP service, and only enable the HTTPS service if you intend to allow users to connect to the router or switch using a web browser.

Next, Cisco Discovery Protocol (CDP), as discussed back in Chapter 10, "Troubleshooting Ethernet LANs," allows devices on the same link to learn basic information from each other. However, that basic information can help an attacker learn some useful information about the network. So, as a security recommendation, Cisco suggests disabling CDP on all interfaces connected to untrusted parts of the network. To be even more secure, CDP could be disabled globally.

> **Note**
>
> In real networks, be careful about turning off CDP on LAN switches until you understand what devices connect to the switch. Many IP phone installations require the use of CDP between the phone and the switch, and without it, the phone does not work.

As one more example, IOS has a set of services that IOS categorizes as small services. For example, the Echo service is one of these small services. It acts a lot like **ping**, with ICMP Echo Request and Echo Reply messages, but unlike these ICMP messages, the Echo application uses either TCP or UDP. So, think of it like a **ping** that also tests the transport layer, while **ping**, which uses ICMP, does not. IOS needs to run the Echo service to be ready to reply to these types of Echo messages.

Some IOS versions leave these services enabled by default, while some do not. To be thorough, disable both TCP and UDP small services.

Example 23-8 shows a configuration on Router R1 that disables the functions mentioned in this section. The notes inside the example explain the specific configuration commands.

Example 23-8. Disabling IOS Services

Click here to view code image

```
! Disable the HTTP service
R1(config)# no ip http server

! Disable small services, both TCP and UDP
R1(config)# no service tcp-small-servers
R1(config)# no service udp-small-servers

! Disable CDP on one interface only; no cdp run would disable
! CDP globally
R1(config)# interface gigabitEthernet 0/0
R1(config-if)# no cdp enable
R1(config-if)# ^Z
```

Controlling Telnet and SSH Access with ACLs

When an external user connects to a router or switch using Telnet or SSH, IOS uses a vty line to represent that user connection. IOS can apply an ACL to those inbound connections by applying an ACL to the vty line, filtering the addresses from which IPv4 hosts can telnet or SSH into the router or switch.

For example, imagine that all the network engineering staff uses subnet 10.1.1.0/24, and only those devices are supposed to be able to telnet into any of the Cisco routers in a network. In such a case, the configuration shown in Example 23-9 could be used on each router to deny access from IP addresses not in that subnet.

Example 23-9. vty Access Control Using the access-class **Command**

Click here to view code image

```
line vty 0 4
login
password cisco
access-class 3 in
!
! Next command is a global command that matches IPv4 packets with
! a source address that begins with 10.1.1.
access-list 3 permit 10.1.1.0 0.0.0.255
```

The **access-class** command refers to the matching logic in **access-list 3**. The keyword **in** refers to Telnet and SSH connections into this router—in other words, people telnetting into this router. As configured, ACL 3 checks the source IP address of packets for incoming Telnet connections.

IOS also supports using ACLs to filter outbound Telnet and SSH connections. For example, consider a user who first uses telnet or SSH to connect to the CLI, and now sits in user or enable mode. With an outbound vty filter, IOS will apply ACL logic if the user tries the **telnet** or **ssh** commands to connect *out of the local device* to another device.

To configure an outbound VTY ACL, use the **access-class** *acl* **out** command in VTY configuration mode. Once configured, the router filters attempts by current vty users to use the **telnet** and **ssh** commands to initiate new connections to other devices.

Of the two options—to protect inbound and outbound connections—protecting inbound connections is by far the more important and more common. However, to be complete, outbound VTY ACLs have a surprising odd feature in how they use the ACL. When using the **out** keyword, the standard IP ACL listed in the **ip access-class** command actually looks at the *destination IP address*, and not the source. That is, it filters based on the device to which the **telnet** or **ssh** command is trying to connect.

ACL Implementation Considerations

ACLs can be a great tool to enhance the security of a network, but engineers should think about some broader issues before simply configuring an ACL to fix a problem. To help, Cisco makes the following general recommendations in the courses on which the CCNA exams are based:

Key Topic

- Place extended ACLs as close as possible to the source of the packet to discard the packets quickly.
- Place standard ACLs as close as possible to the packet's destination, because standard ACLs often discard packets that you do not want discarded when they are placed close to the source.
- Place more specific statements early in the ACL.
- Disable an ACL from its interface (using the **no ip access-group** command) before making changes to the ACL.

The first point deals with the concept of where to locate your ACLs. If you intend to filter a packet, filtering closer to the packet's source means that the packet takes up less bandwidth in the network, which seems to be more efficient—and it is. Therefore, Cisco suggests locating extended ACLs as close to the source as possible.

However, the second point seems to contradict the first point, at least for standard ACLs, to locate them close to the destination. Why? Well, because standard ACLs look only at the source IP address, they tend to filter more than you want filtered when placed close to the source. For example, imagine that Fred and Barney are separated by four routers. If you filter Barney's traffic sent to Fred on the first router, Barney can't reach any hosts near the other three routers. So, the Cisco courses make a blanket recommendation to locate standard ACLs closer to the destination to avoid filtering traffic you don't mean to filter.

For the third item in the list, by placing more specific matching parameters early in each list, you are less likely to make mistakes in the ACL. For example, imagine that the ACL first listed a comment that permitted traffic going to 10.1.1.0/24, and denied traffic going to host 10.1.1.1. Packets sent to host 10.1.1.1 would match the first command, and never match the more specific second command. In general, placing the more specific statements first tends to ensure that you don't miss anything.

Finally, Cisco recommends that you disable the ACLs on the interfaces before you change the statements in the list. Thankfully, if you have an IP ACL enabled on an interface with the **ip access-group** command, and you delete the entire ACL, IOS does not filter any packets. (That was not always the case in earlier IOS versions!) Even so, as soon as you add a command to the ACL, the IOS starts filtering packets.

For example, suppose you have ACL 101 enabled on S0/0/0 for output packets. You delete list 101 so that all packets are allowed through. Then, you enter a single **access-list 101** command. As soon as you press Enter, the list exists, and the router filters all packets exiting S0/0/0 based on the one-line list. If you want to enter a long ACL, you might temporarily filter packets you don't want to filter! Therefore, the better way is to disable the list from the interface, make the changes to the list, and then reenable it on the interface.

Network Time Protocol

The final topic in this chapter shows how to solve an operational problem with log messages that occur on routers and switches. Solving this problem might not appear to be related to security at first, but it actually does play a key role at looking for and correlating the evidence that some kind of attack has happened.

Routers and switches issue log messages in response to different events. For example, when an interface fails, the device creates log messages. With default settings, IOS sends these messages to the console port. IOS can be configured to handle log messages in a variety of ways. The *Cisco CCNA Routing and Switching ICND2 200-101 Official Cert Guide* discusses some of those ways, in Chapter 19 of that book.

One option to handle log messages uses a service called a Syslog server, where the routers and switches forward copies of all log messages to the Syslog server. The Syslog server saves copies of the messages, from all devices. With a centralized location, the network support staff can later look at the messages from all devices, and look at messages that happen at the same time, to discover if a problem has occurred. Figure 23-12 shows the idea, with a Syslog server on the right.

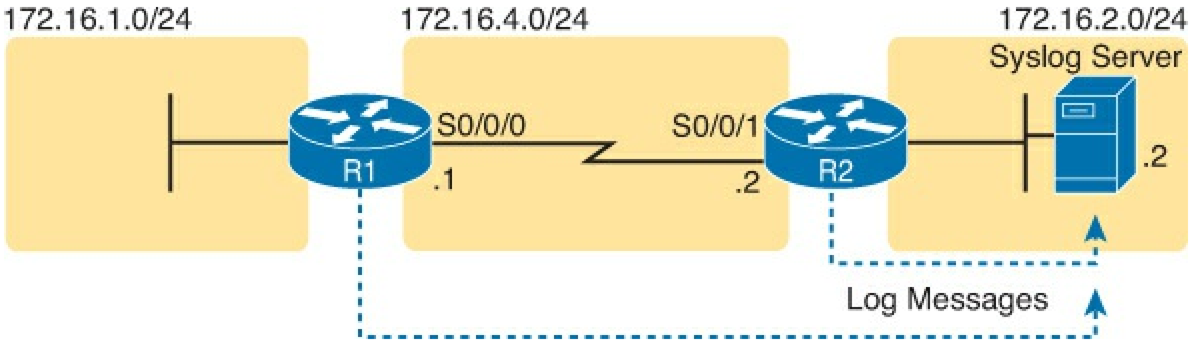


Figure 23-12. Sample Network with a Syslog Server

Armed with that bit of background information about syslog messages, now think about time. In particular, think about the time of day. Each device has a time-of-day clock, and most log messages list the date and time as part of the message. Why? So that when a network engineer looks back at the message, the engineer knows exactly when that message occurred.

Network Time Protocol (NTP) gives any device type, routers and switches included, a way to synchronize their time-of-day clocks. If all the network devices synchronize their clocks, then messages that list the date/time can be viewed so you know which messages happened around the same time, making troubleshooting easier.

To see why synchronizing their clocks matters, consider Example 23-10 in which Routers R1 and R2 do not synchronize their clocks. A problem keeps happening on the serial link between the two routers. A network engineer looks at all the log messages on both devices, as shown in Figure 23-12. However, when the engineer happens to see the messages on R1, at 13:38:39 (around 1:40 p.m.), and other messages from R2 at around 9:45 a.m., the engineer does not correlate the messages as being about the same problem based on the timestamps in the messages.

Example 23-10. Log Messages from Two Routers, Compared

Click here to view code image

```
*Oct 19 13:38:37.568: %OSPF-5-ADJCHG: Process 1, Nbr 2.2.2.2 on Serial0/0/0 from FULL to DOWN, Neighbor Down:
Interface down or detached
*Oct 19 13:38:39.568: %LINK-5-CHANGED: Interface Serial0/0/0, changed state to administratively down
*Oct 19 13:38:40.568: %LINEPROTO-5-UPDOWN: Line protocol on Interface Serial0/0/0, changed state to down
```

```
! These messages happened on router R2
Oct 19 09:44:09.027: %LINK-3-UPDOWN: Interface Serial0/0/1, changed state to down
Oct 19 09:44:09.027: %OSPF-5-ADJCHG: Process 1, Nbr 1.1.1.1 on Serial0/0/1 from FULL to DOWN, Neighbor Down:
Interface down or detached
Oct 19 09:44:10.027: %LINEPROTO-5-UPDOWN: Line protocol on Interface Serial0/0/1, changed state to down
```

As it turns out, the messages in both parts of Figure 23-12 happen within 0.5 seconds of each other, but the two routers' time-of-day clocks were not synchronized. With synchronized clocks, the two routers would have listed a timestamp of almost the exact same time when these messages occurred, making it much easier to read and correlate messages in the future. And for security issues, accurate timestamps let you correlate router and switch log messages with other events logged by other security software and hardware, creating a better defense against attacks.

To configure a router or switch to synchronize its time with an existing NTP server, only a single configuration command is required. Example 23-11 shows router R1 with the **ntp server** command. This command does not make the local device act as an NTP server; instead, it points to the IP address of an NTP server, making the local device act as an NTP client. The server is a device using IP address 172.16.2.2 in this case.

Example 23-11. Configuration and Verification of an NTP Client

Click here to view code image

```
R1# configure terminal
R1(config)# ntp server 172.16.2.2 version 4
R1(config)# ^Z
R1#

R1# show ntp status
Clock is synchronized, stratum 8, reference is 172.16.2.2
nominal freq is 250.0000 Hz, actual freq is 250.0000 Hz, precision is 2**21
ntp uptime is 4700 (1/100 of seconds), resolution is 4000
reference time is D42BD899.5FFCE014 (13:48:09.374 UTC Fri Oct 19 2012)
clock offset is -0.0033 msec, root delay is 1.28 msec
root dispersion is 3938.51 msec, peer dispersion is 187.59 msec
loopfilter state is 'CTRL' (Normal Controlled Loop), drift is 0.000000000 s/s
```

```
system poll interval is 64, last update was 42 sec ago.

R1# show ntp associations

address ref clock st when poll reach delay offset disp
*172.16.2.2 127.127.1.1 7 36 64 1 1.261 -0.001 7937.5
* sys.peer, # selected, + candidate, - outlyer, x falseticker, configured
```

The second part of the example shows two NTP verification commands. First, the output of the **show ntp status** command gives the NTP status in the very first line. In this case, R1 has synchronized its time with the device at 172.16.2.2. This command also lists the current time and date for the timezone configured on the router. The **show ntp associations** command lists a single line of output for each other NTP device with which the router has associated.

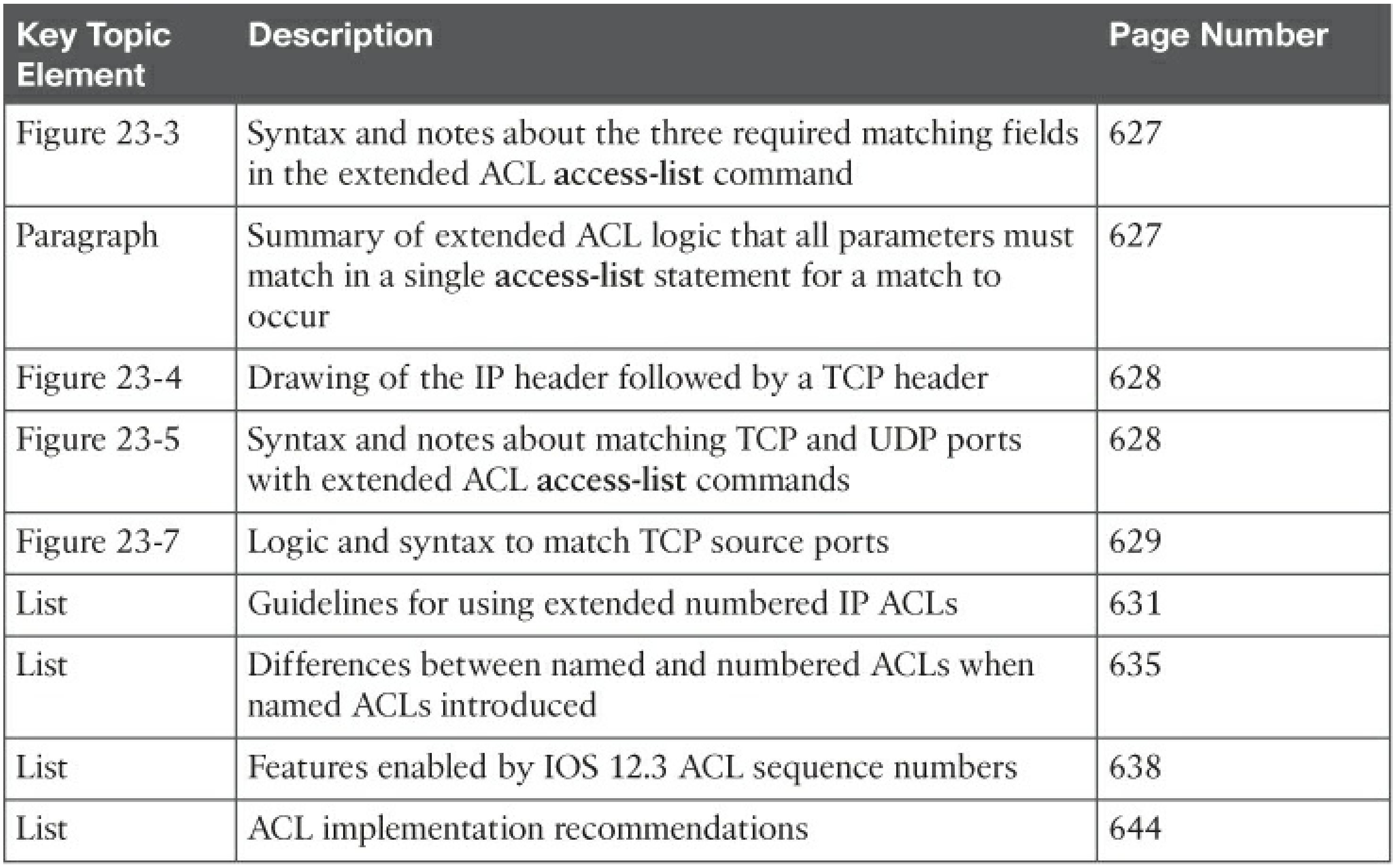
Many variations of NTP configuration exist beyond the simple option shown in Example 23-11. For example, devices can act more like peers, influencing each other's time. Routers and switches can actually be the NTP server with just one command (**ntp master**) as well. And NTP can use authentication so that a router or switch does not get fooled into changing its timestamp, making it more difficult to discover an attack.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 23-7 lists these key topics and where each is discussed.

Table 23-7. Key Topics for Chapter 23



Key Topic Element	Description	Page Number
Figure 23-3	Syntax and notes about the three required matching fields in the extended ACL **access-list** command	627
Paragraph	Summary of extended ACL logic that all parameters must match in a single **access-list** statement for a match to occur	627
Figure 23-4	Drawing of the IP header followed by a TCP header	628
Figure 23-5	Syntax and notes about matching TCP and UDP ports with extended ACL **access-list** commands	628
Figure 23-7	Logic and syntax to match TCP source ports	629
List	Guidelines for using extended numbered IP ACLs	631
List	Differences between named and numbered ACLs when named ACLs introduced	635
List	Features enabled by IOS 12.3 ACL sequence numbers	638
List	ACL implementation recommendations	644

Definitions of Key Terms

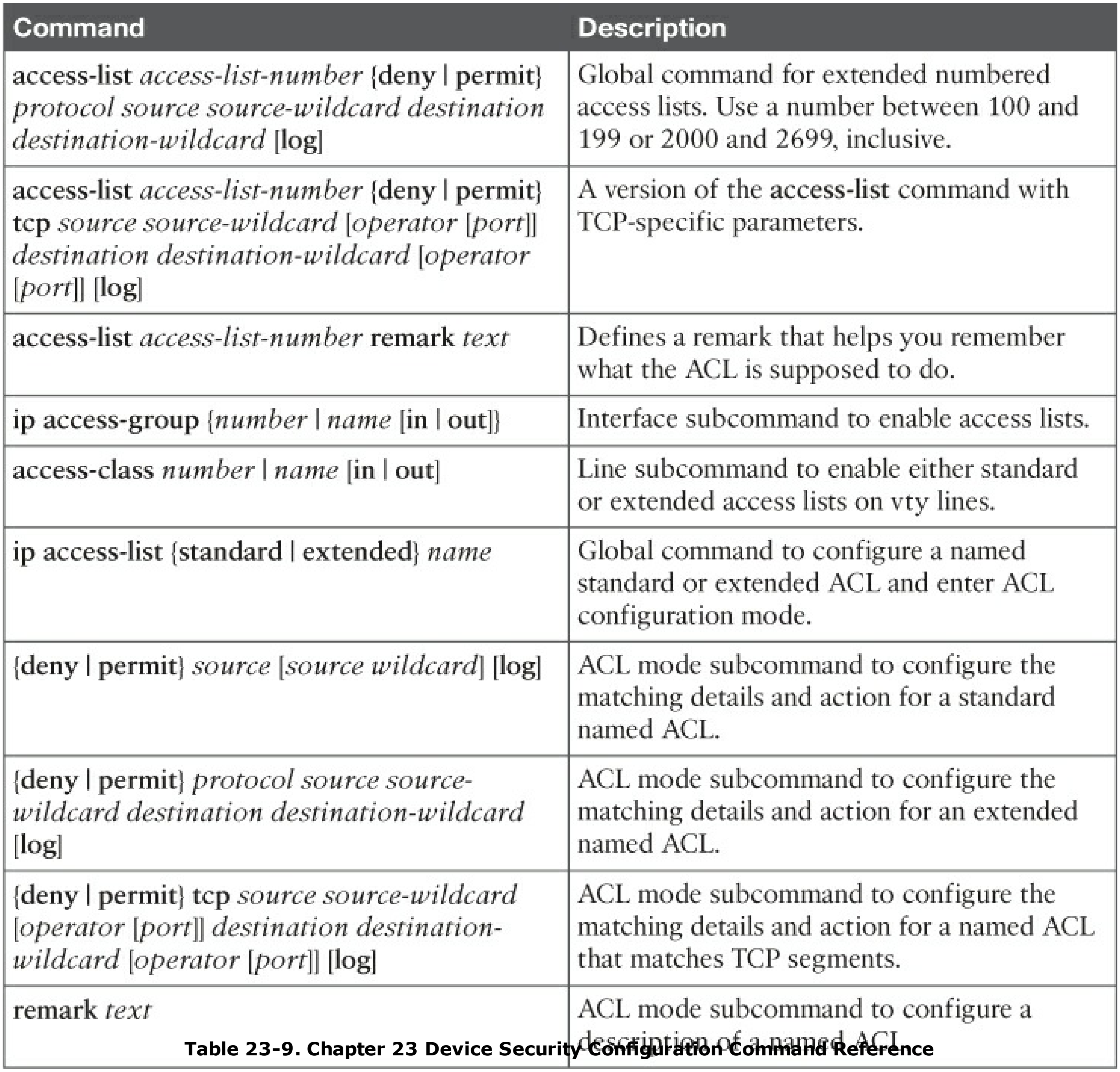
After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

extended access list
named access list
Network Time Protocol (NTP)

Command Reference to Check Your Memory

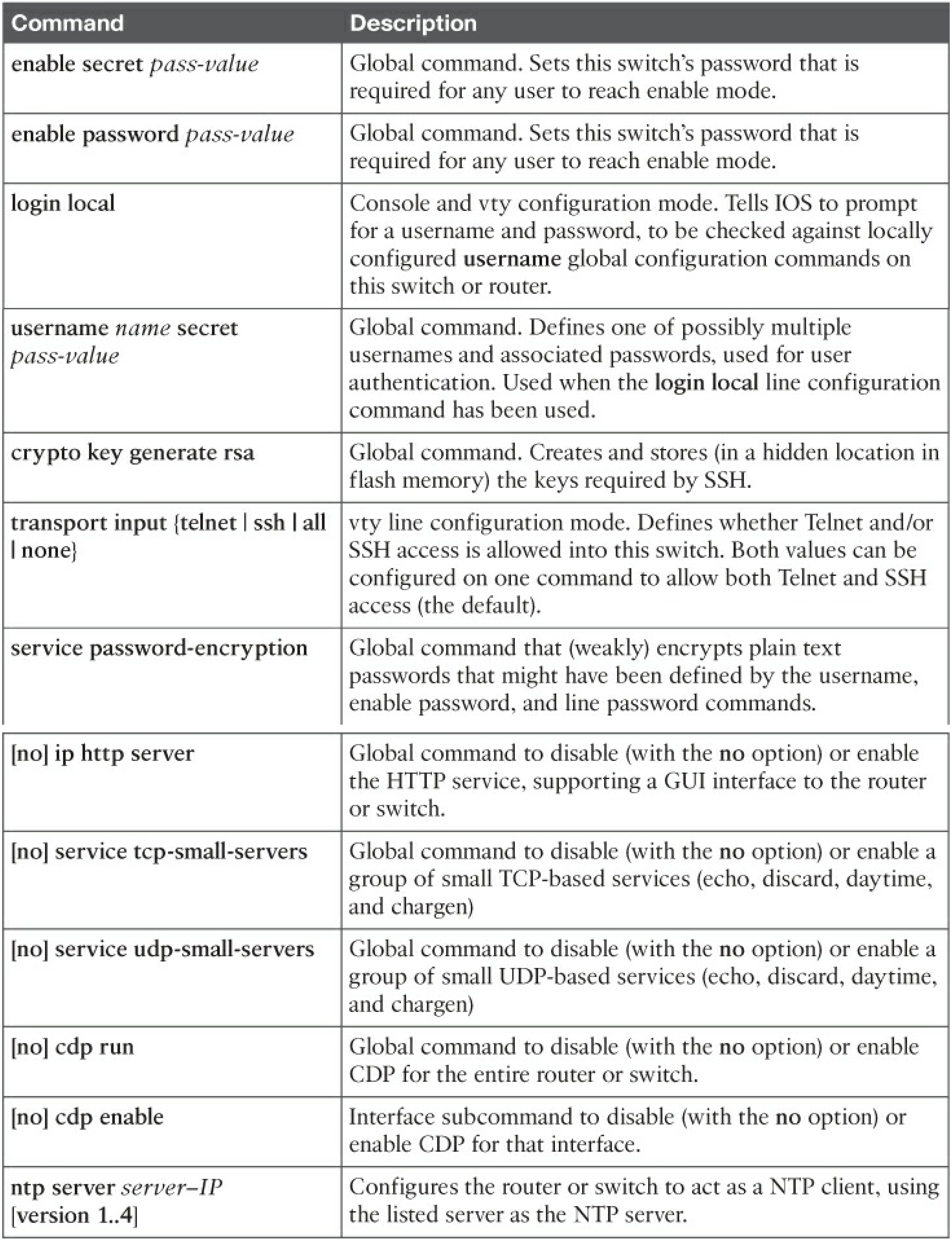
Although you should not necessarily memorize the information in the tables in this section, the following is a reference for the configuration and EXEC commands covered in this chapter.

Table 23-8. Chapter 23 ACL Configuration Command Reference



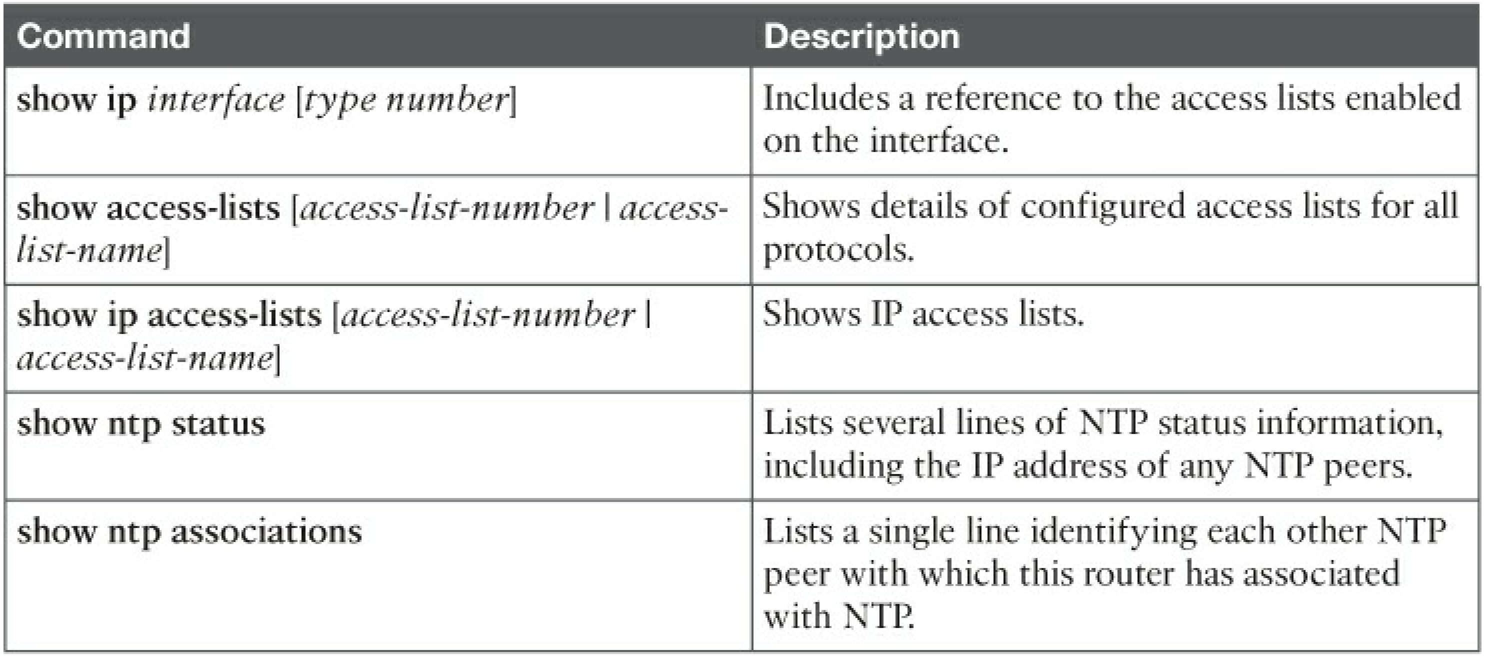
Command	Description
access-list *access-list-number* {**deny** | **permit**} *protocol source source-wildcard destination destination-wildcard* [**log**]	Global command for extended numbered access lists. Use a number between 100 and 199 or 2000 and 2699, inclusive.
access-list *access-list-number* {**deny** | **permit**} **tcp** *source source-wildcard* [*operator* [*port*]] *destination destination-wildcard* [*operator* [*port*]] [**log**]	A version of the **access-list** command with TCP-specific parameters.
access-list *access-list-number* **remark** *text*	Defines a remark that helps you remember what the ACL is supposed to do.
ip access-group {*number* | *name* [**in** | **out**]}	Interface subcommand to enable access lists.
access-class *number* | *name* [**in** | **out**]	Line subcommand to enable either standard or extended access lists on vty lines.
ip access-list {**standard** | **extended**} *name*	Global command to configure a named standard or extended ACL and enter ACL configuration mode.
{**deny** | **permit**} *source* [*source wildcard*] [**log**]	ACL mode subcommand to configure the matching details and action for a standard named ACL.
{**deny** | **permit**} *protocol source source-wildcard destination destination-wildcard* [**log**]	ACL mode subcommand to configure the matching details and action for an extended named ACL.
{**deny** | **permit**} **tcp** *source source-wildcard* [*operator* [*port*]] *destination destination-wildcard* [*operator* [*port*]] [**log**]	ACL mode subcommand to configure the matching details and action for a named ACL that matches TCP segments.
remark *text*	ACL mode subcommand to configure a description of a named ACL.

Table 23-9. Chapter 23 Device Security Configuration Command Reference



Command	Description
enable secret *pass-value*	Global command. Sets this switch's password that is required for any user to reach enable mode.
enable password *pass-value*	Global command. Sets this switch's password that is required for any user to reach enable mode.
login local	Console and vty configuration mode. Tells IOS to prompt for a username and password, to be checked against locally configured **username** global configuration commands on this switch or router.
username *name* **secret** *pass-value*	Global command. Defines one of possibly multiple usernames and associated passwords, used for user authentication. Used when the **login local** line configuration command has been used.
crypto key generate rsa	Global command. Creates and stores (in a hidden location in flash memory) the keys required by SSH.
transport input {**telnet** | **ssh** | **all** | **none**}	vty line configuration mode. Defines whether Telnet and/or SSH access is allowed into this switch. Both values can be configured on one command to allow both Telnet and SSH access (the default).
service password-encryption	Global command that (weakly) encrypts plain text passwords that might have been defined by the username, enable password, and line password commands.
[no] ip http server	Global command to disable (with the **no** option) or enable the HTTP service, supporting a GUI interface to the router or switch.
[no] service tcp-small-servers	Global command to disable (with the **no** option) or enable a group of small TCP-based services (echo, discard, daytime, and chargen)
[no] service udp-small-servers	Global command to disable (with the **no** option) or enable a group of small UDP-based services (echo, discard, daytime, and chargen)
[no] cdp run	Global command to disable (with the **no** option) or enable CDP for the entire router or switch.
[no] cdp enable	Interface subcommand to disable (with the **no** option) or enable CDP for that interface.
ntp server *server–IP* [**version 1..4**]	Configures the router or switch to act as a NTP client, using the listed server as the NTP server.

Table 23-10. Chapter 23 EXEC Command Reference

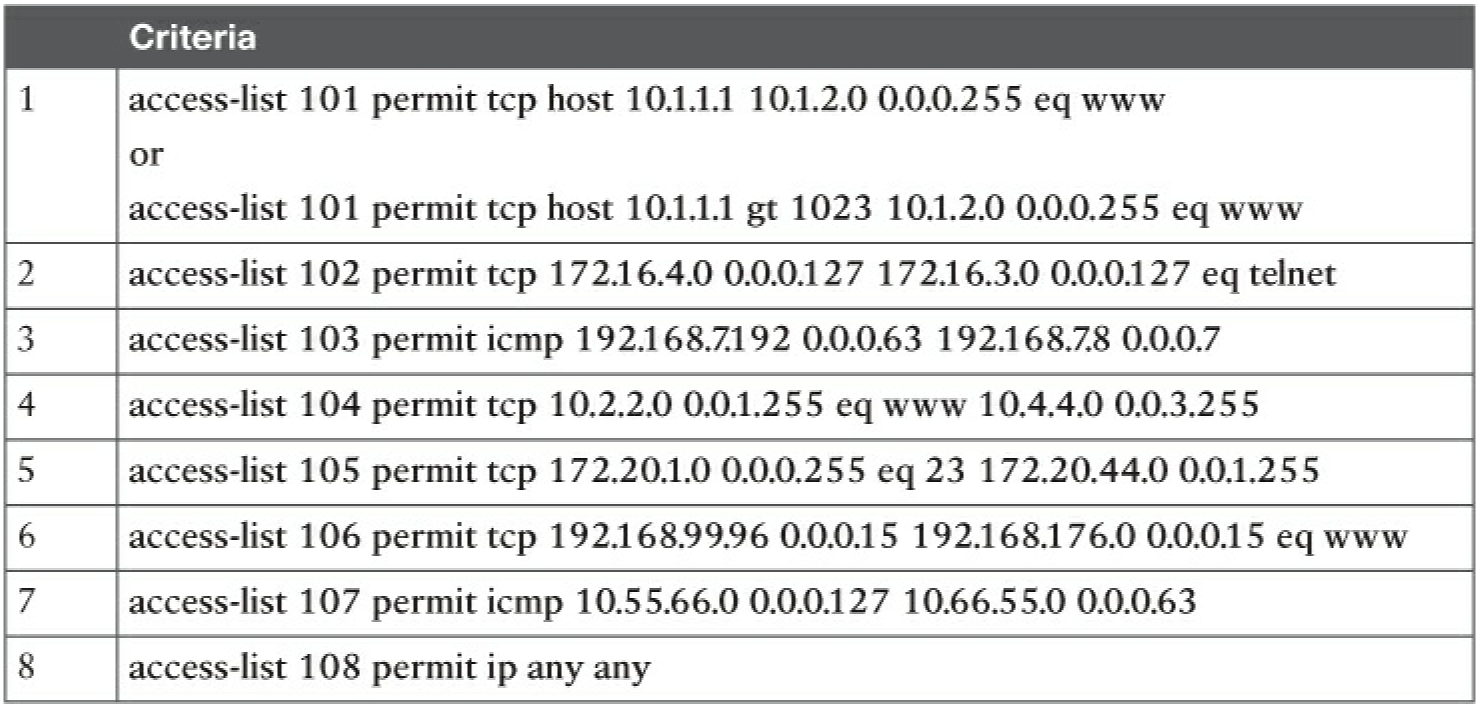


Command	Description
show ip *interface* [*type number*]	Includes a reference to the access lists enabled on the interface.
show access-lists [*access-list-number* | *access-list-name*]	Shows details of configured access lists for all protocols.
show ip access-lists [*access-list-number* | *access-list-name*]	Shows IP access lists.
show ntp status	Lists several lines of NTP status information, including the IP address of any NTP peers.
show ntp associations	Lists a single line identifying each other NTP peer with which this router has associated with NTP.

Answers to Earlier Practice Problems

Table 23-11 lists the answers to the practice problems listed in Table 23-6. Note that for any question that references a client, you might have chosen to match port numbers greater than 1023. The answers in this table mostly ignore that option, but just to show one sample, the answer to the first problem lists one with a reference to client ports greater than 1023 and one without. The remaining answers simply omit this part of the logic.

Table 23-11. Building One-Line Extended ACLs: Answers



	Criteria
1	access-list 101 permit tcp host 10.1.1.1 10.1.2.0 0.0.0.255 eq www or access-list 101 permit tcp host 10.1.1.1 gt 1023 10.1.2.0 0.0.0.255 eq www
2	access-list 102 permit tcp 172.16.4.0 0.0.0.127 172.16.3.0 0.0.0.127 eq telnet
3	access-list 103 permit icmp 192.168.7.192 0.0.0.63 192.168.7.8 0.0.0.7
4	access-list 104 permit tcp 10.2.2.0 0.0.1.255 eq www 10.4.4.0 0.0.3.255
5	access-list 105 permit tcp 172.20.1.0 0.0.0.255 eq 23 172.20.44.0 0.0.1.255
6	access-list 106 permit tcp 192.168.99.96 0.0.0.15 192.168.176.0 0.0.0.15 eq www
7	access-list 107 permit icmp 10.55.66.0 0.0.0.127 10.66.55.0 0.0.0.63
8	access-list 108 permit ip any any

Chapter 24. Network Address Translation

This chapter covers the following subjects:

- **Operation of IP Data Networks**
  - Predict the data flow between two hosts across a network
- **IP Services**
  - Identify the basic operation of NAT
  - Purpose
  - Pool
  - Static
  - 1 to 1
  - Overloading
  - Source addressing
  - One way NAT
  - Configure and verify NAT for given network requirements

This last of the chapters about IPv4 topics looks at a very popular and very important part of both enterprise and small office/home office (SOHO) networks: Network Address Translation, or NAT. NAT helped solve a big problem with IPv4: The IPv4 address space would have been completely consumed by the mid-1990s. After it was consumed, the Internet could not continue to grow, which would have significantly slowed the development of the Internet.

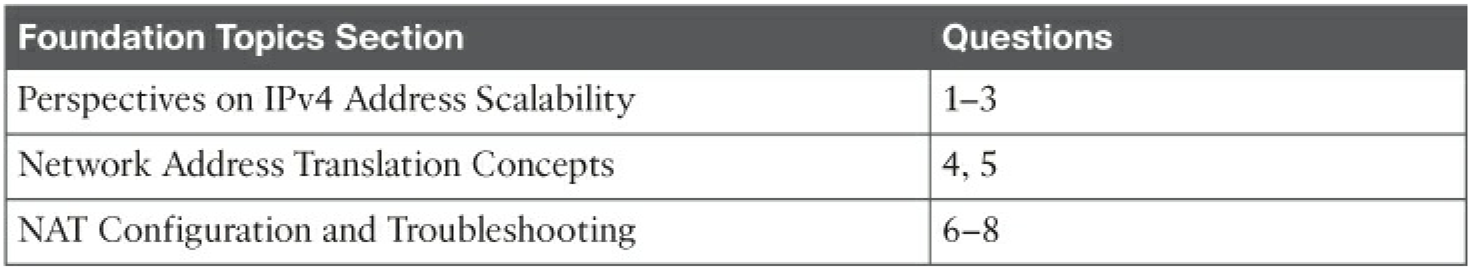
This chapter actually discusses two short-term solutions to the IPv4 address exhaustion issue, which also serves as a good lead-in to IP version 6 (IPv6). NAT, along with classless interdomain routing (CIDR), helped extend the life of IPv4 as the network layer protocol of the Internet from the 1990s into the 2010s. Part VII of this book discusses the long-term solution that will become the standard for the Internet: IP version 6 (IPv6).

This chapter breaks the topics into three major sections. The first section explains the challenges to the IPv4 address space caused by the Internet revolution of the 1990s. The second section explains the basic concept behind NAT, how several variations of NAT work, and how the Port Address Translation (PAT) option conserves the IPv4 address space. The final section shows how to configure NAT from the Cisco IOS Software command-line interface (CLI), and how to troubleshoot NAT.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 24-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Perspectives on IPv4 Address Scalability	1–3
Network Address Translation Concepts	4, 5
NAT Configuration and Troubleshooting	6–8

1. What does CIDR stand for?
   a. Classful IP default routing
   b. Classful IP D-class routing
   c. Classful interdomain routing
   d. Classless IP default routing
   e. Classless IP D-class routing
   f. Classless interdomain routing
2. Which of the following summarized subnets represent routes that could have been created for CIDR's goal to reduce the size of Internet routing tables?
   a. 10.0.0.0 255.255.255.0
   b. 10.1.0.0 255.255.0.0
   c. 200.1.1.0 255.255.255.0
   d. 200.1.0.0 255.255.0.0
3. Which of the following are not private addresses according to RFC 1918? (Choose two answers.)

a. 172.31.1.1

b. 172.33.1.1

c. 10.255.1.1

d. 10.1.255.1

e. 191.168.1.1

4. With static NAT, performing translation for inside addresses only, what causes NAT table entries to be created?

a. The first packet from the inside network to the outside network

b. The first packet from the outside network to the inside network

c. Configuration using the **ip nat inside source** command

d. Configuration using the **ip nat outside source** command

5. With dynamic NAT, performing translation for inside addresses only, what causes NAT table entries to be created?

a. The first packet from the inside network to the outside network

b. The first packet from the outside network to the inside network

c. Configuration using the **ip nat inside source** command

d. Configuration using the **ip nat outside source** command

6. NAT has been configured to translate source addresses of packets for the inside part of the network, but only for some hosts as identified by an access control list. Which of the following commands indirectly identifies the hosts?

a. ip nat inside source list 1 pool barney

b. ip nat pool barney 200.1.1.1 200.1.1.254 netmask 255.255.255.0

c. ip nat inside

d. ip nat inside 200.1.1.1 200.1.1.2

7. Examine the following configuration commands:

Click here to view code image

```
interface Ethernet0/0
ip address 10.1.1.1 255.255.255.0
ip nat inside
interface Serial0/0
ip address 200.1.1.249 255.255.255.252
ip nat inside source list 1 interface Serial0/0
access-list 1 permit 10.1.1.0 0.0.0.255
```

If the configuration is intended to enable source NAT overload, which of the following commands could be useful to complete the configuration? (Choose two answers.)

a. The **ip nat outside** command

b. The **ip nat pat** command

c. The **overload** keyword

d. The **ip nat pool** command

8. Examine the following **show** command output on a router configured for dynamic NAT:

Click here to view code image

```
-- Inside Source
access-list 1 pool fred refcount 2288
pool fred: netmask 255.255.255.240
start 200.1.1.1 end 200.1.1.7
type generic, total addresses 7, allocated 7 (100%), misses 965
```

Users are complaining about not being able to reach the Internet. Which of the following is the most likely cause?

a. The problem is not related to NAT, based on the information in the command output.

b. The NAT pool does not have enough entries to satisfy all requests.

c. Standard ACL 1 cannot be used; an extended ACL must be used.

d. The command output does not supply enough information to identify the problem.

Answers to the “Do I Know This Already?” quiz:

1 F **2** D **3** B and E **4** C **5** A **6** A **7** A and C **8** B

Foundation Topics

Perspectives on IPv4 Address Scalability

The original design for the Internet required every organization to ask for, and receive, one or more registered classful IP network numbers. The people administering the program ensured that none of the IP networks were reused. As long as every organization used only IP addresses inside its own registered network numbers, IP addresses would never be duplicated, and IP routing could work well.

Connecting to the Internet using only a registered network number, or several registered network numbers, worked well for a while. In the early to mid-1990s, it became apparent that the Internet was growing so fast that all IP network numbers would be assigned by the mid-1990s! Concern arose that the available networks would be completely assigned, and some organizations would not be able to connect to the Internet.

The main long-term solution to the IP address scalability problem was to increase the size of the IP address. This one fact was the most compelling reason for the advent of IP version 6 (IPv6). (Version 5 was defined much earlier, but was never deployed, so the next attempt was labeled as version 6.) IPv6 uses a 128-bit address, instead of the 32-bit address in IPv4. With the same or improved process of assigning unique address ranges to every organization connected to the Internet, IPv6 can easily support every organization and individual on the planet, with the number of IPv6 addresses theoretically reaching above 10^{38}.

Many short-term solutions to the addressing problem were suggested, but three standards worked together to solve the problem. Two of the standards work closely together: Network Address Translation (NAT) and private addressing. These features together allow organizations to use unregistered IP network numbers internally and still communicate well with the Internet. The third standard, classless interdomain routing (CIDR), allows ISPs to reduce the wasting of IP addresses by assigning a company a subset of a network number rather than the entire network. CIDR also can allow ISPs to summarize routes such that multiple Class A, B, or C networks match a single route, which helps reduce the size of Internet routing tables.

Note

These tools have worked well. Estimates in the early 1990s predicted that the world would run out of IPv4 addresses by the mid-1990s, but IANA did not exhaust the IPv4 address space until February 2011.

CIDR

CIDR is a global address assignment convention that defines how the Internet Assigned Numbers Authority (IANA), its member agencies, and ISPs should assign the globally unique IPv4 address space to individual organizations.

CIDR, defined in RFC 4632, has two main goals. First, CIDR defines a way to assign public IP addresses, worldwide, to allow route aggregation or route summarization. These route summaries greatly reduce the size of routing tables in Internet routers. Second, CIDR defines rules that allow an ISP to assign public IP addresses in blocks other than an entire Class A, B, or C network. CIDR allows ISPs to assign a public IPv4 address block of a size that better matches the needs of that customer.

Route Aggregation for Shorter Routing Tables

Imagine a router in the Internet, with a route to every Class A, B, and C network on the planet. More than 2 million Class C networks exist! If Internet routers had to list every classful network in their routing tables, the routers would require a lot of memory, and routing table searches would require a lot of processing power.

CIDR defines a route aggregation or summarization strategy for the routes to public IPv4 addresses in the Internet. This strategy relies on a worldwide IPv4 address assignment strategy, as well as some simple math to replace many routes for smaller ranges of addresses with one route for a larger range of addresses.

Figure 24-1 shows a typical case of how CIDR might be used to replace over 65,000 routes with one route. First, imagine that ISP 1 owns Class C networks 198.0.0.0 through 198.255.255.0 (these might look funny, but they are valid Class C network numbers). In other words, IANA assigned all addresses that begin with 198 to one of the five regional numbering authorities, and that organization assigned this entire range to one big ISP in that part of the world. This assignment idea is part of CIDR, because it then allows route summarization.

Key Topic

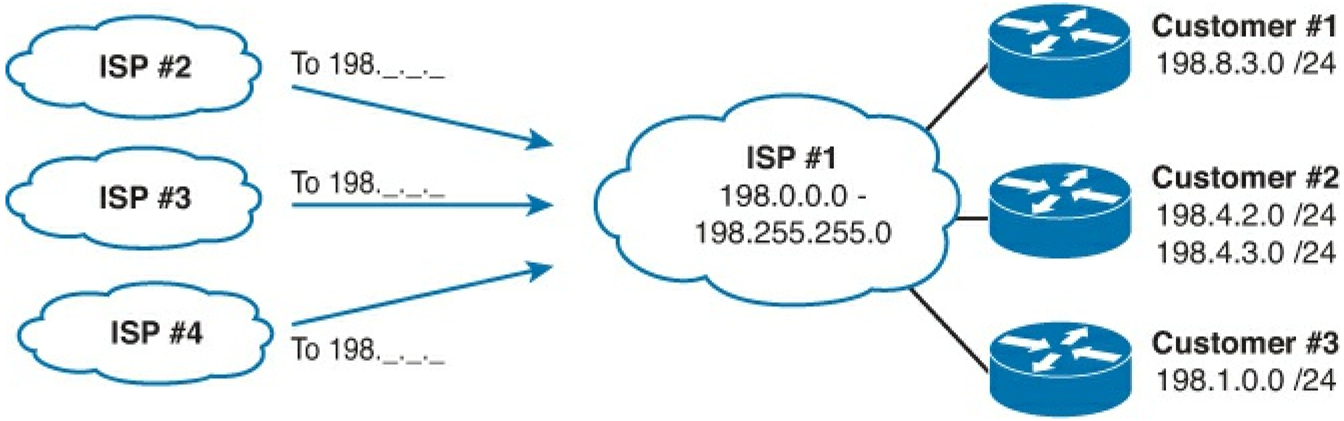


Figure 24-1. Typical Use of CIDR

CIDR then defines how to create one route for all of the 2^{16} Class C networks that begin with 198. Figure 24-1 shows the ISPs on the left each with one route to 198.0.0.0/8—in other words, a route to all hosts whose IP address begins with 198. 65,536 Class C IP networks begin with 198, and this one summary route represents all those IP networks.

CIDR requires the use of a classless routing protocol, which, by definition, means that the routing protocol sends the mask along with each route. Classless routing protocols treat each route more like a math problem, ignoring the Class A, B, and C rules. For example, 198.0.0.0/8 (198.0.0.0, mask 255.0.0.0) defines a set of addresses whose first 8 bits are equal to decimal 198. ISP 1 advertises this route to the other ISPs, which need a route only to 198.0.0.0/8. In its routers, ISP 1 knows which Class C networks are at which customer sites. This is how CIDR gives Internet routers a much more scalable routing table—by reducing the number of entries in the tables.

IPv4 Address Conservation

CIDR also helps reduce the chance of our running out of IPv4 addresses by allowing an ISP to allocate a subset of a Class A, B, or C network to a single customer. For example, imagine that ISP 1's customer 1 needs only ten IP addresses and that customer 3 needs 25 IP addresses. ISP 1 does something like this: It assigns IP subnet 198.8.3.16/28, with assignable addresses 198.8.3.17 to 198.8.3.30, to customer 1. For customer 3, ISP 1 suggests 198.8.3.32/27, with 30 assignable addresses (198.8.3.33 to 198.8.3.62). The ISP has met the customers' needs and still not used all of Class C network 198.8.3.0.

CIDR helps prevent the wasting of IP addresses, thereby reducing the need for registered IP network numbers. Instead of two customers consuming two entire Class C networks, each consumes a small portion of a single Class C network. At the same time, CIDR, along with the intelligent administration of consecutive network numbers to each ISP, allows the Internet routing table to support a much smaller routing table in Internet routers than would otherwise be required.

Private Addressing

Some computers might never be connected to the Internet. These computers' IP addresses could be duplicates of registered IP addresses in the Internet. When designing the IP addressing convention for such a network, an organization could pick and use any network number(s) it wanted, and all would be well. For example, you can buy a few routers, connect them in your office, and configure IP addresses in network 1.0.0.0, and it would work. The IP addresses you use might be duplicates of real IP addresses in the Internet, but if all you want to do is learn on the lab in your office, everything will be fine.

When building a private network that will have no Internet connectivity, you can use IP network numbers called *private internets*, as defined in RFC 1918, "Address Allocation for Private Internets." This RFC defines a set of networks that will never be assigned to any organization as a registered network number. Instead of using someone else's registered network numbers, you can use numbers in a range that are not used by anyone else in the public Internet. Table 24-2 shows the private address space defined by RFC 1918.

Key Topic

Table 24-2. RFC 1918 Private Address Space

Range of IP Addresses	Class of Networks	Number of Networks
10.0.0.0 to 10.255.255.255	A	1
172.16.0.0 to 172.31.255.255	B	16
192.168.0.0 to 192.168.255.255	C	256

In other words, any organization can use these network numbers. However, no organization is allowed to advertise these networks using a routing protocol on the Internet.

You might be wondering why you would bother to reserve special private network numbers when it doesn't matter whether the addresses are duplicates. Well, as it turns out, you can use private addressing in an internetwork, and connect to the Internet at the same time, as long as you use Network Address Translation (NAT). The rest of this chapter examines and explains NAT.

Network Address Translation Concepts

NAT, defined in RFC 3022, allows a host that does not have a valid, registered, globally unique IP address to communicate with other hosts through the Internet. The hosts might be using private addresses or addresses assigned to another organization. In either case, NAT allows these addresses that are not Internet ready to continue to be used and still allows communication with hosts across the Internet.

NAT achieves its goal by using a valid registered IP address to represent the private address to the rest of the Internet. The NAT function changes the private IP addresses to publicly registered IP addresses inside each IP packet, as shown in Figure 24-2.

Key Topic

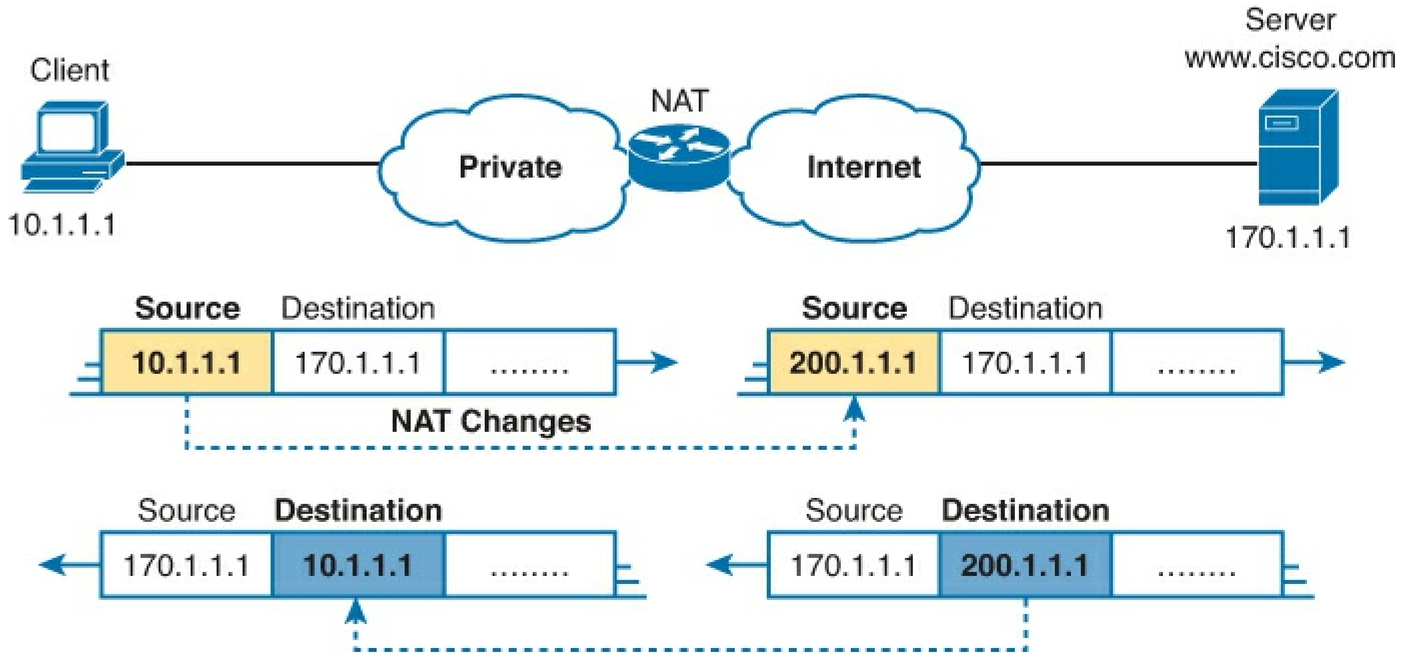


Figure 24-2. NAT IP Address Swapping: Private Addressing

Notice that the router, performing NAT, changes the packet's source IP address when the packet leaves the private organization. The router performing NAT also changes the destination address in each packet that is forwarded back into the private network. (Network 200.1.1.0 is a registered network in Figure 24-2.) The NAT feature, configured in the router labeled NAT, performs the translation.

Cisco IOS Software supports several variations of NAT. The next few pages cover the concepts behind several of these variations. The section after that covers the configuration related to each option.

Static NAT

Static NAT works just like the example shown in Figure 24-2, but with the IP addresses statically mapped to each other. To help you understand the implications of static NAT and to explain several key terms, Figure 24-3 shows a similar example with more information.

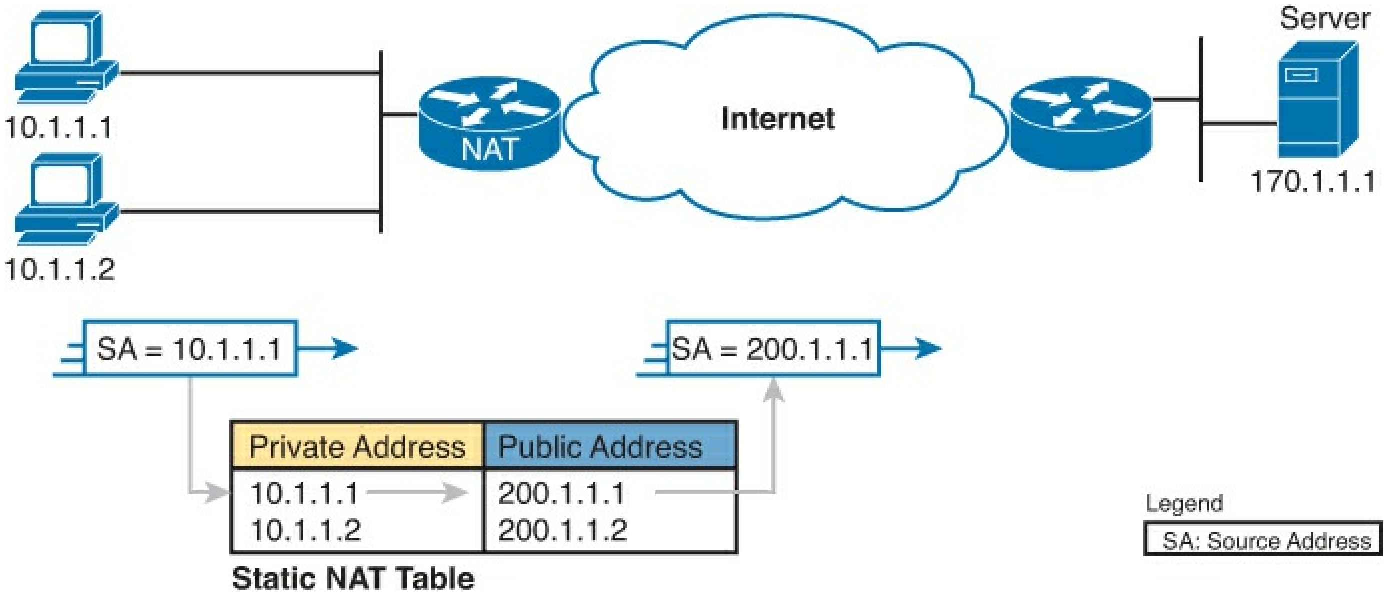

10.1.1.1
10.1.1.2
NAT
Internet
Server
170.1.1.1
SA = 10.1.1.1
SA = 200.1.1.1
Private Address
Public Address
10.1.1.1
10.1.1.2
200.1.1.1
200.1.1.2
Static NAT Table
Legend
SA: Source Address

Figure 24-3. Static NAT Showing Inside Local and Global Addresses

First, the concepts: The company's ISP has assigned it registered network 200.1.1.0. Therefore, the NAT router must make the private IP addresses look like they are in network 200.1.1.0. To do so, the NAT router changes the source IP addresses in the packets going from left to right in the figure.

In this example, the NAT router changes the source address ("SA" in the figure) of 10.1.1.1 to 200.1.1.1. With static NAT, the NAT router simply configures a one-to-one mapping between the private address and the registered address that is used on its behalf. The NAT router has statically configured a mapping between private address 10.1.1.1 and public, registered address 200.1.1.1.

Supporting a second IP host with static NAT requires a second static one-to-one mapping using a second IP address in the public address range. For example, to support 10.1.1.2, the router statically maps 10.1.1.2 to 200.1.1.2. Because the enterprise has a single registered Class C network, it can support at most 254 private IP addresses with NAT, with the usual two reserved numbers (the network number and network broadcast address).

The terminology used with NAT, particularly with configuration, can be a little confusing. Notice in Figure 24-3 that the NAT table lists the private IP addresses as "private" and the public, registered addresses from network 200.1.1.0 as "public." Cisco uses the term *inside local* for the private IP addresses in this example and *inside global* for the public IP addresses.

Using NAT terminology, the enterprise network that uses private addresses, and therefore needs NAT, is the "inside" part of the network. The Internet side of the NAT function is the "outside" part of the network. A host that needs NAT (such as 10.1.1.1 in the example) has the IP address it uses inside the network, and it needs an IP address to represent it in the outside network. So, because the host essentially needs two different addresses to represent it, you need two terms. Cisco calls the private IP address used in the inside network the *inside local* address and the address used to represent the host to the rest of the Internet the *inside global* address. Figure 24-4 repeats the same example, with some of the terminology shown.

Key Topic

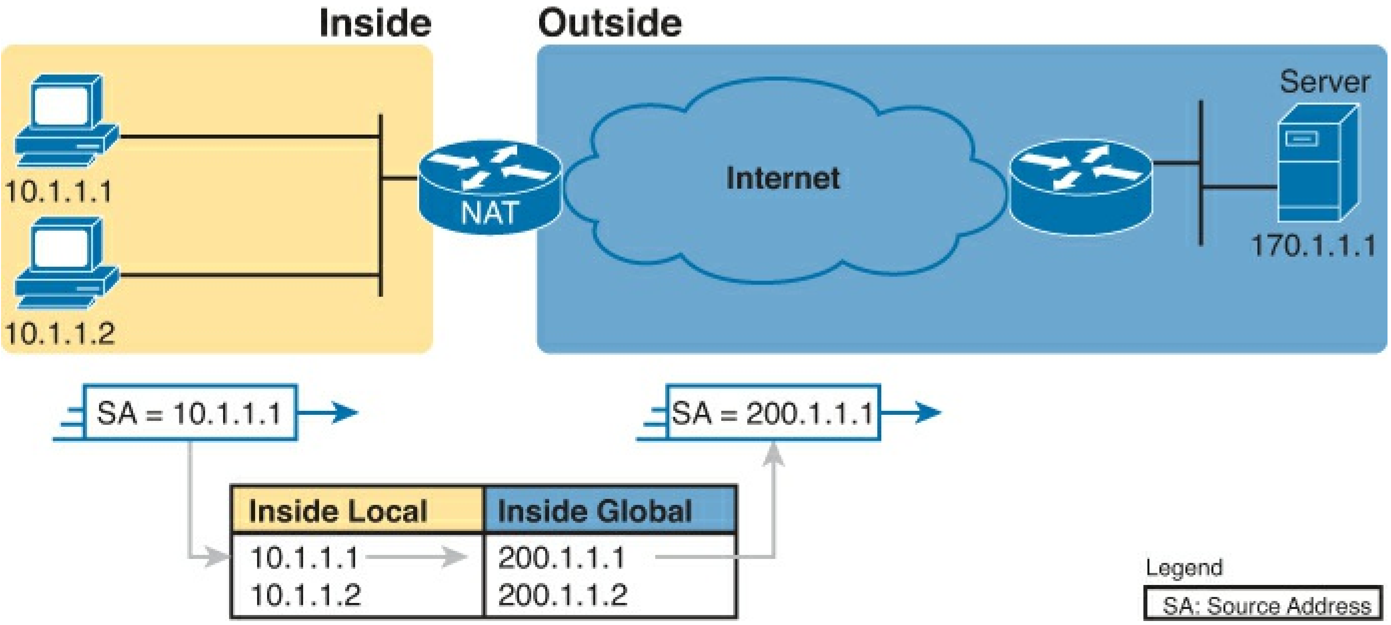
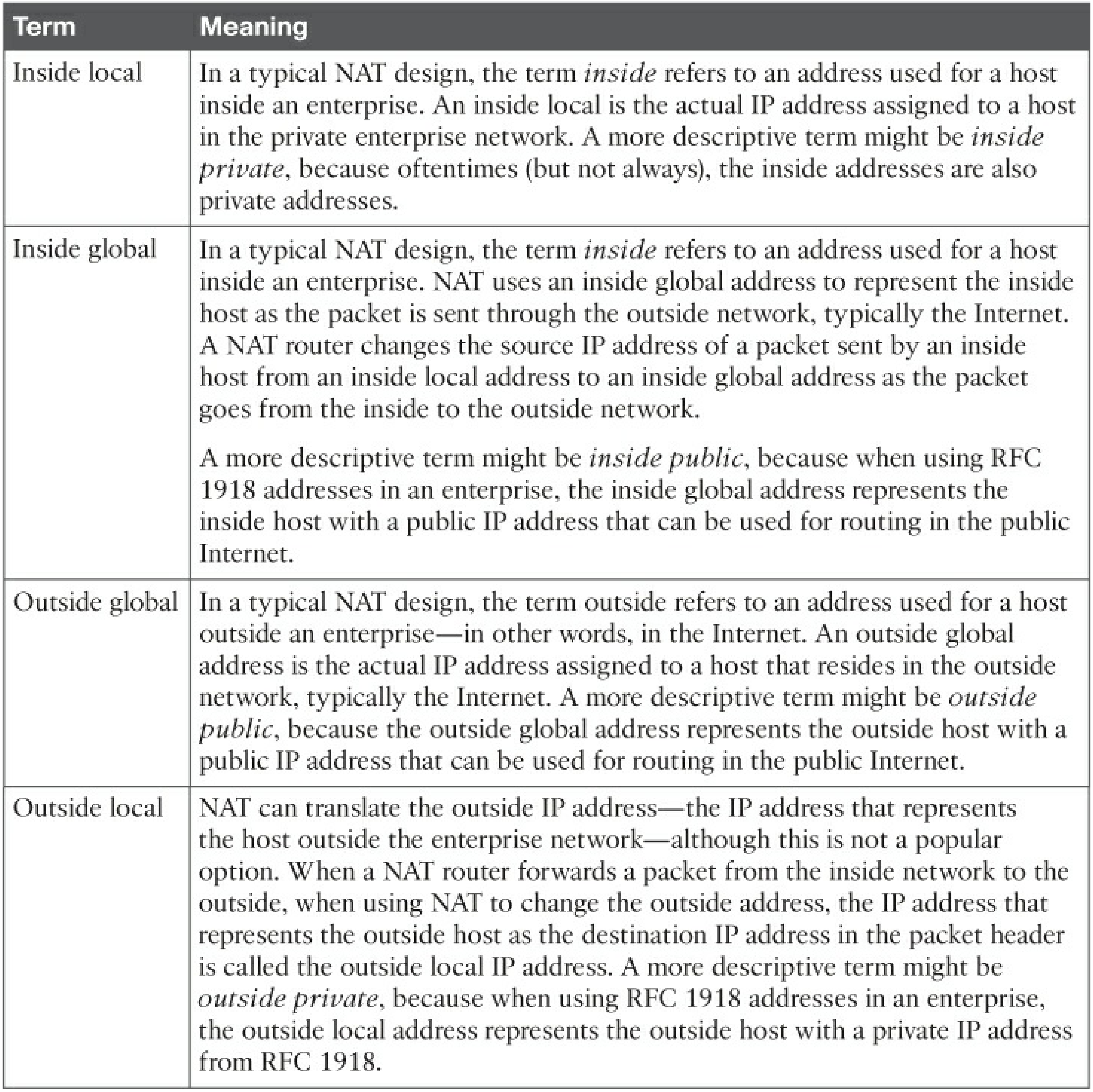

Inside
Outside
10.1.1.1
10.1.1.2
NAT
Internet
Server
170.1.1.1
SA = 10.1.1.1
SA = 200.1.1.1
Inside Local
Inside Global
10.1.1.1
10.1.1.2
200.1.1.1
200.1.1.2
Legend
SA: Source Address

Figure 24-4. Static NAT Terminology

Most typical NAT configurations change only the IP address of inside hosts. Therefore, the current NAT table shown in Figure 24-4 shows the inside local and corresponding inside global registered addresses. However, the outside host IP address can also be changed with NAT. When that occurs, the terms *outside local* and *outside global* denote the IP address used to represent that host in the inside network and the outside network, respectively. Table 24-3 summarizes the terminology and meanings.

Table 24-3. NAT Addressing Terms



Term	Meaning
Inside local	In a typical NAT design, the term *inside* refers to an address used for a host inside an enterprise. An inside local is the actual IP address assigned to a host in the private enterprise network. A more descriptive term might be *inside private*, because oftentimes (but not always), the inside addresses are also private addresses.
Inside global	In a typical NAT design, the term *inside* refers to an address used for a host inside an enterprise. NAT uses an inside global address to represent the inside host as the packet is sent through the outside network, typically the Internet. A NAT router changes the source IP address of a packet sent by an inside host from an inside local address to an inside global address as the packet goes from the inside to the outside network. A more descriptive term might be *inside public*, because when using RFC 1918 addresses in an enterprise, the inside global address represents the inside host with a public IP address that can be used for routing in the public Internet.
Outside global	In a typical NAT design, the term outside refers to an address used for a host outside an enterprise—in other words, in the Internet. An outside global address is the actual IP address assigned to a host that resides in the outside network, typically the Internet. A more descriptive term might be *outside public*, because the outside global address represents the outside host with a public IP address that can be used for routing in the public Internet.
Outside local	NAT can translate the outside IP address—the IP address that represents the host outside the enterprise network—although this is not a popular option. When a NAT router forwards a packet from the inside network to the outside, when using NAT to change the outside address, the IP address that represents the outside host as the destination IP address in the packet header is called the outside local IP address. A more descriptive term might be *outside private*, because when using RFC 1918 addresses in an enterprise, the outside local address represents the outside host with a private IP address from RFC 1918.

Dynamic NAT

Dynamic NAT has some similarities and differences compared to static NAT. Like static NAT, the NAT router creates a one-to-one mapping between an inside local and inside global address, and changes the IP addresses in packets as they exit and enter the inside network. However, the mapping of an inside local address to an inside global address happens dynamically.

Dynamic NAT sets up a pool of possible inside global addresses and defines matching criteria to determine which inside local IP addresses should be translated with NAT. For example, in Figure 24-5, a pool of five inside global IP addresses has been established: 200.1.1.1 through 200.1.1.5. NAT has also been configured to translate any inside local addresses that start with 10.1.1.

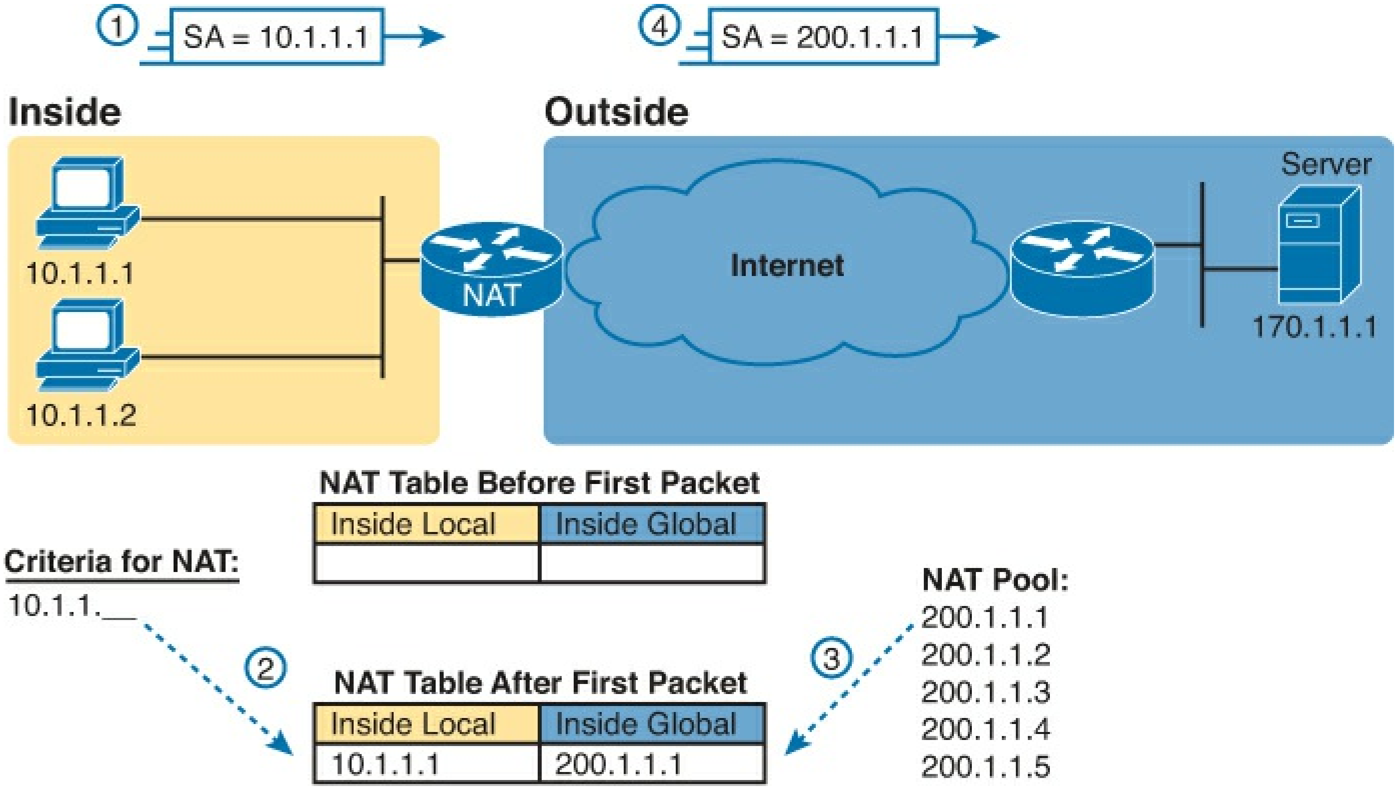


Figure 24-5. Dynamic NAT

The numbers 1, 2, 3, and 4 in the figure refer to the following sequence of events:

1. Host 10.1.1.1 sends its first packet to the server at 170.1.1.1.
2. As the packet enters the NAT router, the router applies some matching logic to decide whether the packet should have NAT applied. Because the logic has been configured to match source IP addresses that begin with 10.1.1, the router adds an entry in the NAT table for 10.1.1.1 as an inside local address.
3. The NAT router needs to allocate an IP address from the pool of valid inside global addresses. It picks the first one available (200.1.1.1, in this case) and adds it to the NAT table to complete the entry.
4. The NAT router translates the source IP address and forwards the packet.

The dynamic entry stays in the table as long as traffic flows occasionally. You can configure a timeout value that defines how long the router should wait, having not translated any packets with that address, before removing the dynamic entry. You can also manually clear the dynamic entries from the table using the **clear ip nat translation *** command.

NAT can be configured with more IP addresses in the inside local address list than in the inside global address pool. The router allocates addresses from the pool until all are allocated. If a new packet arrives from yet another inside host, and it needs a NAT entry, but all the pooled IP addresses are in use, the router simply discards the packet. The user must try again until a NAT entry times out, at which point the NAT function works for the next host that sends a packet. Essentially, the inside global pool of addresses needs to be as large as the maximum number of concurrent hosts that need to use the Internet at the same time—unless you use PAT, as is explained in the next section.

Overloading NAT with Port Address Translation (PAT)

Some networks need to have most, if not all, IP hosts reach the Internet. If that network uses private IP addresses, the NAT router needs a very large set of registered IP addresses. With static NAT, for each private IP host that needs Internet access, you need a publicly registered IP address, completely defeating the goal of reducing the number of public IPv4 addresses needed for that organization. Dynamic NAT lessens the problem to some degree, because every single host in an internetwork should seldom need to communicate with the Internet at the same time. However, if a large percentage of the IP hosts in a network will need Internet access throughout that company’s normal business hours, NAT still requires a large number of registered IP addresses, again failing to reduce IPv4 address consumption.

The NAT Overload feature, also called Port Address Translation (PAT), solves this problem. Overloading allows NAT to scale to support many clients with only a few public IP addresses.

The key to understanding how overloading works is to recall how hosts use TCP and User Datagram Protocol (UDP) ports. To see why, first consider the idea of three separate TCP connections to a web server, from three different hosts, as shown in Figure 24-6.

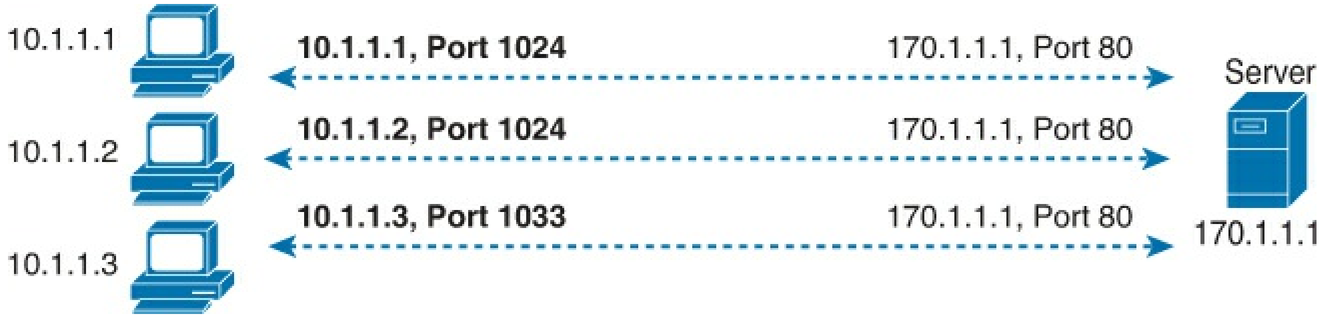

10.1.1.1
10.1.1.1, Port 1024
170.1.1.1, Port 80
Server
10.1.1.2
10.1.1.2, Port 1024
170.1.1.1, Port 80
10.1.1.3
10.1.1.3, Port 1033
170.1.1.1, Port 80
170.1.1.1

Figure 24-6. Three TCP Connections from Three PCs

Next, compare those three TCP connections in Figure 24-6 to three similar TCP connections, now with all three TCP connections from one client, as shown in Figure 24-7. The server does realize a difference, because the server see the IP address and TCP port number used by the clients in both figures. However, the server really does not care whether the TCP connections come from different hosts, or the same host; the server just sends and receives data over each connection.

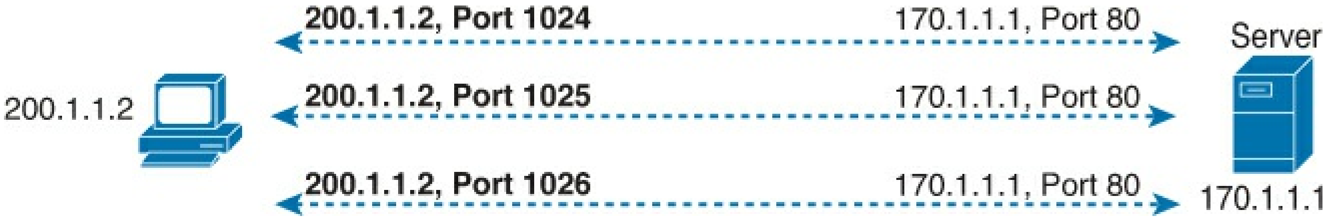
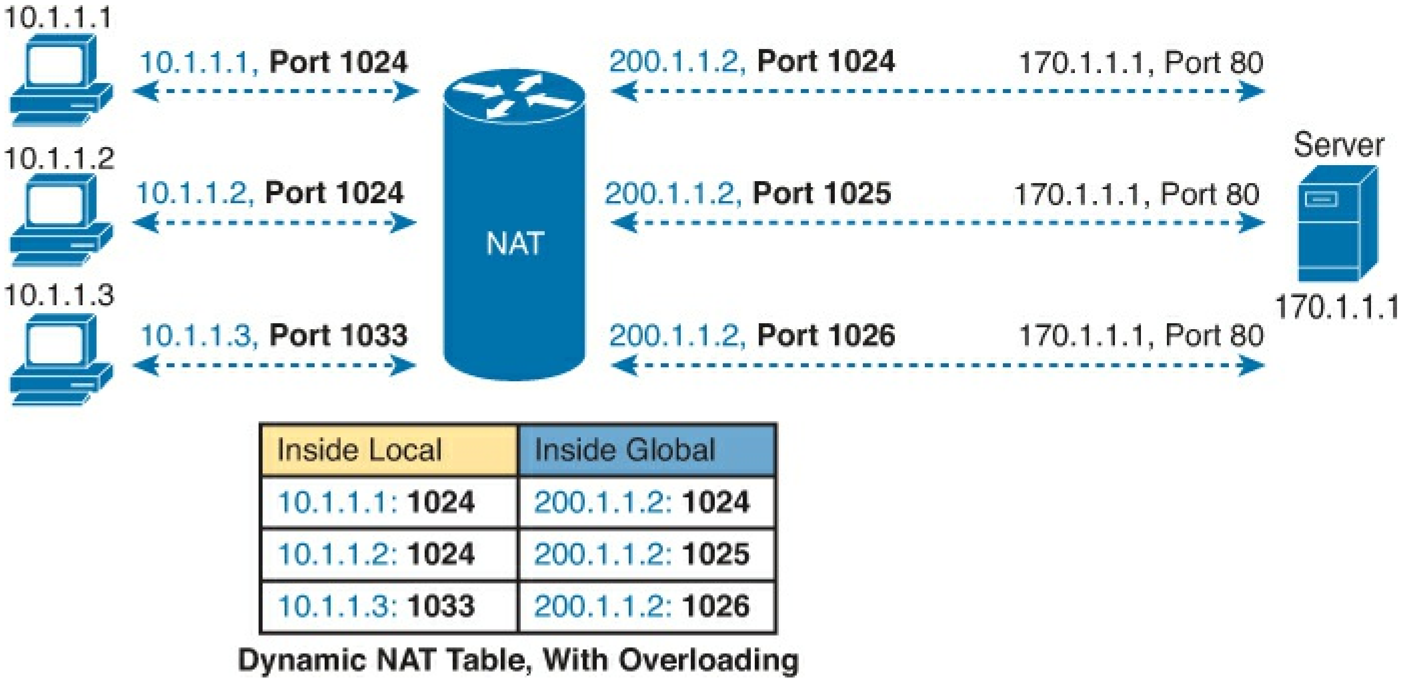

200.1.1.2, Port 1024
170.1.1.1, Port 80
Server
200.1.1.2
200.1.1.2, Port 1025
170.1.1.1, Port 80
200.1.1.2, Port 1026
170.1.1.1, Port 80
170.1.1.1

Figure 24-7. Three TCP Connections from One PC

NAT takes advantage of the fact that, from a transport layer perspective, the server doesn't care whether it has one connection each to three different hosts or three connections to a single host IP address. NAT overload (PAT) translates not only the address, but the port number when necessary, making what looks like many TCP or UDP flows from different hosts look like the same number of flows from one host. Figure 24-8 outlines the logic.

Key Topic


10.1.1.1
10.1.1.1, Port 1024
200.1.1.2, Port 1024
170.1.1.1, Port 80
10.1.1.2
10.1.1.2, Port 1024
NAT
200.1.1.2, Port 1025
170.1.1.1, Port 80
Server
170.1.1.1
10.1.1.3
10.1.1.3, Port 1033
200.1.1.2, Port 1026
170.1.1.1, Port 80

Inside Local	Inside Global
10.1.1.1: 1024	200.1.1.2: 1024
10.1.1.2: 1024	200.1.1.2: 1025
10.1.1.3: 1033	200.1.1.2: 1026

Dynamic NAT Table, With Overloading

Figure 24-8. NAT Overload (PAT)

When PAT creates the dynamic mapping, it selects not only an inside global IP address but also a unique port number to use with that address. The NAT router keeps a NAT table entry for every unique combination of inside local IP address and port, with translation to the inside global address and a unique port number associated with the inside global address. And because the port number field has 16 bits, NAT overload can use more than 65,000 port numbers, allowing it to scale well without needing many registered IP addresses—in many cases, needing only one inside global IP address.

Of the three types of NAT covered in this chapter so far, PAT is by far the most popular option. Static NAT and Dynamic NAT both require a one-to-one mapping from the inside local to the inside global address. PAT significantly reduces the number of required registered IP addresses compared to these other NAT alternatives.

NAT Overload (PAT) on Consumer Routers

The (upcoming) last major section of this chapter shows how to configure and verify NAT overload, or PAT, on an enterprise-class Cisco router. However, consumer-grade Cisco routers enable many features by default, including PAT. The strategy with consumer-grade routers allows the consumer to just physically install the router and cables, without needing to configure the router. This topic discusses how these consumer-grade routers work to enable PAT, even when using defaults.

First, as mentioned way back in Chapter 3, "Fundamentals of WANs." products sold in the store as a "router" actually have many features: a router, a LAN switch, often with a wireless LAN access point, and a security firewall. They often include the PAT function as well. As for hardware, these routers have several RJ-45 ports labeled as "LAN"; these are ports for the LAN switch function. They also have one RJ-45 port labeled "WAN," which is another Ethernet port that acts like a router interface, typically connected to a DSL or cable modem which in turn connects to the Internet, as shown in Figure 24-9.

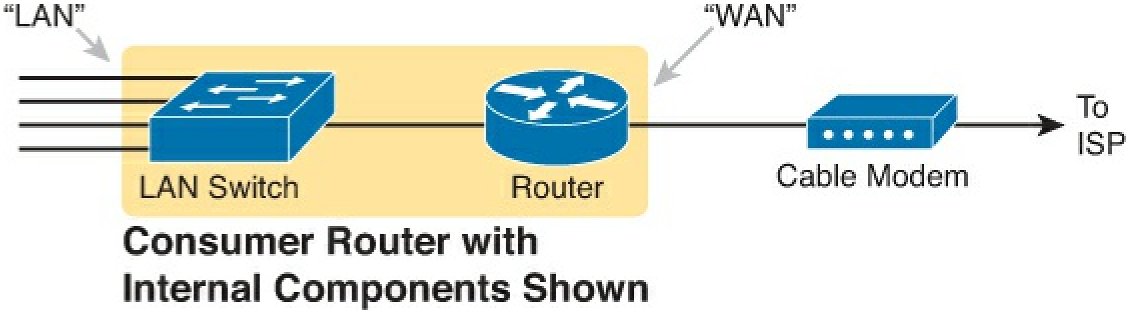


Figure 24-9. Consumer "Router" with LAN and WAN Ports

To understand how a consumer router does PAT by default, you first need to understand how it does DHCP. The router acts as a DHCP server on the LAN side, using a private IP network prechosen by the router vendor. (Cisco products often use private Class C network 192.168.1.0.) Then, on the WAN side, the router acts as a DHCP client, leasing an IP address from the ISP's DHCP server. But the address learned from the ISP is not a private IP address, but a public IPv4 address, as shown in Figure 24-10.

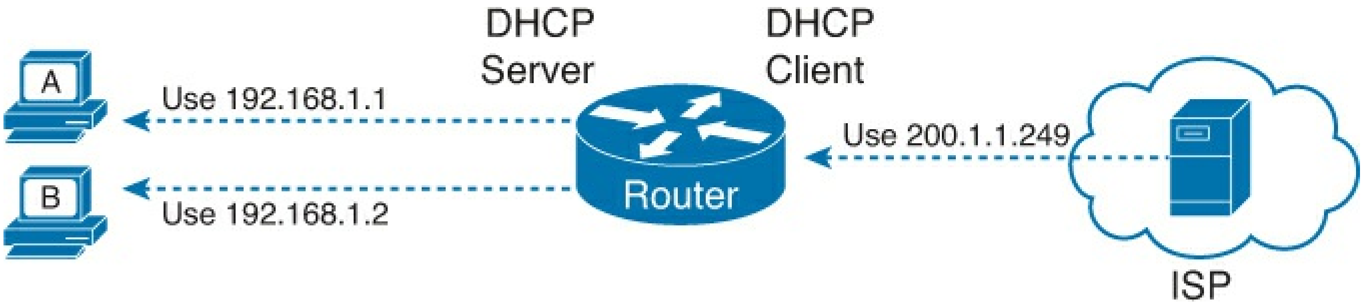


Figure 24-10. Consumer Router as DHCP Server on LAN, DHCP Client on WAN

> **Note**
>
> To make an enterprise-class router act like the router in Figure 24-10, on the WAN port, use the **ip address dhcp** interface subcommand. This command simply tells the router to learn its own interface IP address with DHCP. The DHCP server configuration would use the same commands detailed in Chapter 18, "Configuring and Verifying Host Connectivity."

By using DHCP on both the LAN and WAN sides, a consumer router has created a perfect match of IP addresses to use PAT. The computers on the LAN all have private IP addresses, and the one WAN port has a public IP address. All the consumer router has to do is enable PAT, with the LAN side of the router as the NAT inside, and the WAN port on the NAT outside, as shown in Figure 24-11.

Key Topic

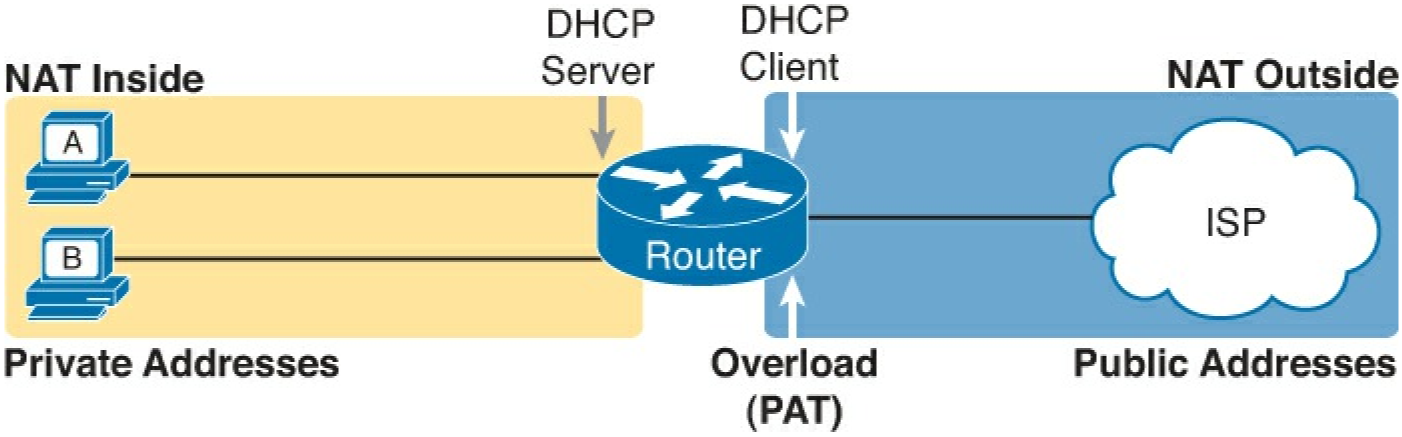


Figure 24-11. Locations of DHCP and NAT/PAT Roles in a Consumer Router

NAT Configuration and Troubleshooting

In the following sections, you read about how to configure the three most common variations of NAT: static NAT, dynamic NAT, and PAT, along with the **show** and **debug** commands used to troubleshoot NAT.

Static NAT Configuration

Static NAT configuration, as compared to the other variations of NAT, requires the fewest configuration steps. Each static mapping between a local (private) address and a global (public) address must be configured. Additionally, the router must be told on which interfaces it should use NAT, because NAT does not have to be enabled on every interface. In particular, the router needs to know each interface and whether the interface is an inside or outside interface. The specific steps are as follows:

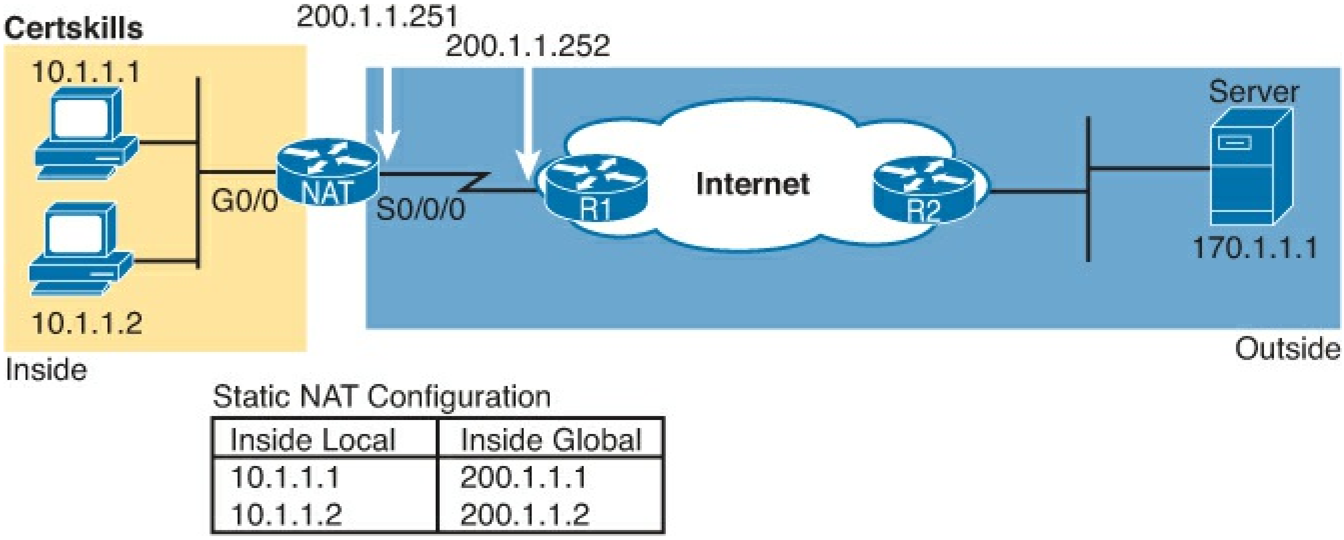
Key Topic

Step 1. Configure interfaces to be in the inside part of the NAT design using the **ip nat inside** interface subcommand.

Step 2. Configure interfaces to be in the outside part of the NAT design using the **ip nat outside** interface subcommand.

Step 3. Configure the static mappings with the **ip nat inside source static** *inside-local inside-global* global configuration command.

Figure 24-12 shows the familiar network used in the description of static NAT earlier in this chapter, which is also used for the first several configuration examples. In Figure 24-12, you can see that Certskills has obtained Class C network 200.1.1.0 as a registered network number. That entire network, with mask 255.255.255.0, is configured on the serial link between Certskills and the Internet. With a point-to-point serial link, only two of the 254 valid IP addresses in that network are consumed, leaving 252 addresses.



Inside Local	Inside Global
10.1.1.1	200.1.1.1
10.1.1.2	200.1.1.2

Figure 24-12. Sample Network for NAT Examples, with Public Class C 200.1.1.0/24

When planning a NAT configuration, you must find some IP addresses to use as inside global IP addresses. Because these addresses must be part of some registered IP address range, it is common to use the extra addresses in the subnet connecting the enterprise to the Internet—for example, the extra 252 IP addresses in network 200.1.1.0 in this case. The router can also be configured with a loopback interface and assigned an IP address that is part of a globally unique range of registered IP addresses.

Example 24-1 lists the NAT configuration, using 200.1.1.1 and 200.1.1.2 for the two static NAT mappings.

Example 24-1. Static NAT Configuration

Click here to view code image

```
NAT# show running-config
!
! Lines omitted for brevity
!
interface GigabitEthernet0/0
ip address 10.1.1.3 255.255.255.0
ip nat inside
!
interface Serial0/0/0
ip address 200.1.1.251 255.255.255.0
ip nat outside
!
ip nat inside source static 10.1.1.2 200.1.1.2
ip nat inside source static 10.1.1.1 200.1.1.1

NAT# show ip nat translations
Pro Inside global Inside local Outside local Outside global
--- 200.1.1.1 10.1.1.1 --- ---
--- 200.1.1.2 10.1.1.2 --- ---

NAT# show ip nat statistics
Total active translations: 2 (2 static, 0 dynamic; 0 extended)
Outside interfaces:
Serial0/0/0
Inside interfaces:
GigabitEthernet0/0
Hits: 100 Misses: 0
Expired translations: 0
Dynamic mappings:
```

The static mappings are created using the **ip nat inside source static** command. The **inside** keyword means that NAT translates addresses for hosts on the inside part of the network. The **source** keyword means that NAT translates the source IP address of packets coming into its inside interfaces. The **static** keyword means that the parameters define a static entry, which should never be removed from the NAT table because of timeout. Because the design calls for two hosts, 10.1.1.1 and 10.1.1.2, to have Internet access, two **ip nat inside** commands are needed.

After creating the static NAT entries, the router needs to know which interfaces are "inside" and which are "outside." The **ip nat inside** and **ip nat outside** interface subcommands identify each interface appropriately.

A couple of **show** commands list the most important information about NAT. The **show ip nat translations** command lists the two static NAT entries created in the configuration. The **show ip nat statistics** command lists statistics, listing things such as the number of currently active translation table entries. The statistics also include the number of hits, which increments for every packet for which NAT must translate addresses.

Dynamic NAT Configuration

As you might imagine, dynamic NAT configuration differs in some ways from static NAT, but it has some similarities as well. Dynamic NAT still requires that each interface be identified as either an inside or outside interface, and of course static mapping is no longer required. Dynamic NAT uses an access control list (ACL) to identify which inside local (private) IP addresses need to have their addresses translated, and it defines a pool of registered public IP addresses to allocate. The specific steps are as follows:

Key Topic

Step 1. As with static NAT, configure interfaces to be in the inside part of the NAT design using the **ip nat inside** interface subcommand.

Step 2. As with static NAT, configure interfaces to be in the outside part of the NAT design using the **ip nat outside** interface subcommand.

Step 3. Configure an ACL that matches the packets entering inside interfaces for which NAT should be performed.

Step 4. Configure the pool of public registered IP addresses using the **ip nat pool** *name first-address last-address* **netmask** *subnet-mask* global configuration command.

Step 5. Enable dynamic NAT by referencing the ACL (Step 3) and pool (Step 4) with the **ip nat inside source list** *acl-number* **pool** *pool-name* global configuration command.

The next example shows a sample dynamic NAT configuration using the same network topology as the previous example (see Figure 24-12). In this case, the same two inside local addresses, 10.1.1.1 and 10.1.1.2, need translation. However, unlike the previous static NAT example, the configuration in Example 24-2 places the public IP addresses (200.1.1.1 and 200.1.1.2) into a pool of dynamically assignable inside global addresses.

Example 24-2. Dynamic NAT Configuration

Click here to view code image

```
NAT# show running-config
!
! Lines omitted for brevity
!
interface GigabitEthernet0/0
ip address 10.1.1.3 255.255.255.0
ip nat inside
!
interface Serial0/0/0
ip address 200.1.1.251 255.255.255.0
ip nat outside
!
ip nat pool fred 200.1.1.1 200.1.1.2 netmask 255.255.255.252
ip nat inside source list 1 pool fred
!
access-list 1 permit 10.1.1.2
access-list 1 permit 10.1.1.1
```

Dynamic NAT configures the pool of public (global) addresses with the **ip nat pool** command listing the first and last numbers in an inclusive range of inside global addresses. For example, if the pool needed ten addresses, the command might have listed 200.1.1.1 and 200.1.1.10, which means that NAT can use 200.1.1.1 and 200.1.1.10.

Dynamic NAT also performs a verification check on the **ip nat pool** command with the required **netmask** parameter. If the address range would not be in the same subnet, assuming the configured **netmask** was used on the addresses in the configured range, then IOS will reject the **ip nat pool** command. For example, as configured with the low end of 200.1.1.1, high end of 200.1.1.2, and a mask of 255.255.255.252, IOS would use the following checks, to ensure that both calculates put 200.1.1.1 and 200.1.1.2 in the same subnet:

- 200.1.1.1 with mask 255.255.255.252 implies subnet 200.1.1.0, broadcast address 200.1.1.3.
- 200.1.1.2 with mask 255.255.255.252 implies subnet 200.1.1.0, broadcast address 200.1.1.3.

If the command had instead showed a low and high end value of 200.1.1.1 and 200.1.1.6, again with mask 255.255.255.252, IOS would reject the command. IOS would do the math spelled out in the following list, realizing that the numbers were in different subnets:

- 200.1.1.1 with mask 255.255.255.252 implies subnet 200.1.1.0, broadcast address 200.1.1.3.
- 200.1.1.6 with mask 255.255.255.252 implies subnet 200.1.1.4, broadcast address 200.1.1.7.

One other big different between the dynamic NAT and static NAT configuration in Example 24-1 has to do with two options in the **ip nat inside source** command. The dynamic NAT version of this command refers to the name of the NAT pool it wants to use for inside global addresses—in this case, fred. It also refers to an IP ACL, which defines the matching logic for inside local IP addresses. So, the logic for the **ip nat inside source list 1 pool fred** command in this example is:

> Create NAT table entries that map between hosts matched by ACL 1, for packets entering any inside interface, allocating an inside global address from the pool called fred.

Dynamic NAT Verification

Examples 24-3 and 24-4 show the evidence that dynamic NAT begins with no NAT table entries, but the router reacts after user traffic correctly drives the NAT function. Example 24-3 shows the output of the **show ip nat translations** and **show ip nat statistics** commands before any users generate traffic that makes NAT do some work. The **show ip nat translations** command, which lists the NAT table entries, lists a blank line; the **show ip nat statistics** command, which shows how many times NAT has created a NAT table entry, shows 0 active translations.

Example 24-3. Dynamic NAT Verifications Before Generating Traffic

Click here to view code image

```
! The next command lists one empty line because no entries have been dynamically
! created yet.
```

```
NAT# show ip nat translations

NAT# show ip nat statistics
Total active translations: 0 (0 static, 0 dynamic; 0 extended)
Outside interfaces:
Serial0/0
Inside interfaces:
Ethernet0/0
Hits: 0 Misses: 0
CEF Translated packets: 0, CEF Punted packets: 0
Expired translations: 0
Dynamic mappings:
-- Inside Source
[id 1] access-list 1 pool fred refcount 0
pool fred: netmask 255.255.255.252
start 200.1.1.1 end 200.1.1.2
type generic, total addresses 2, allocated 0 (0%), misses 0

Total doors: 0
Appl doors: 0
Normal doors: 0
Queued Packets: 0
```

The **show ip nat statistics** command at the end of the example lists some particularly interesting troubleshooting information with two different counters labeled “misses,” as highlighted in the example. The first occurrence of this counter counts the number of times a new packet comes along, needing a NAT entry, and not finding one. At that point, dynamic NAT reacts and builds an entry. The second misses counter toward the end of the command output lists the number of misses in the pool. This counter only increments when dynamic NAT tries to allocate a new NAT table entry and finds no available addresses, so the packet cannot be translated—probably resulting in an end user not getting to the application.

Next, Example 24-4 updates the output of both commands after the user of host at 10.1.1.1 telnets to host 170.1.1.1.

Example 24-4. Dynamic NAT Verifications After Generating Traffic

Click here to view code image

```
NAT# show ip nat translations
Pro Inside global Inside local Outside local Outside global
--- 200.1.1.1 10.1.1.1 --- ---

NAT# show ip nat statistics
Total active translations: 1 (0 static, 1 dynamic; 0 extended)
Outside interfaces:
Serial0/0
Inside interfaces:
Ethernet0/0
Hits: 69 Misses: 1
Expired translations: 0
Dynamic mappings:
-- Inside Source
access-list 1 pool fred refcount 1
pool fred: netmask 255.255.255.252
start 200.1.1.1 end 200.1.1.2
type generic, total addresses 2, allocated 1 (50%), misses 0
```

The example begins with host 10.1.1.1 telnetting to 170.1.1.1 (not shown), with the NAT router creating a NAT entry. The NAT table shows a single entry, mapping 10.1.1.1 to 200.1.1.1. And, the first line in the output of the **show ip nat translations** command lists a counter for 1 active translation, as seen in the NAT table at the top of the example.

Take an extra moment to consider the last highlighted line, where the **show ip nat statistics** command lists 1 miss and 69 hits. The first miss counter, now at 1, means that one packet arrived that needed NAT but there was no NAT table entry. NAT reacted and added a NAT table entry, so the hit counter of 69 means that the next 69 packets used the newly added NAT table entry. The second misses counter, still at 0, did not increment because the NAT pool had enough available inside global IP addresses to use to allocate the new NAT table entry. Also note that the last line lists statistics on the number of pool members allocated (1) and the percentage of the pool currently in use (50%).

The dynamic NAT table entries time out after a period of inactivity, putting those inside global addresses back in the pool for future use. Example 24-5 shows a sequence in which two different hosts make use of inside global address 200.1.1.1. Host 10.1.1.1 uses inside global address 200.1.1.1 at the beginning of the example. Then, instead of just waiting on the NAT entry to time out, the example clears the NAT table entry with the **clear ip nat translation *** command. At that point, the user at 10.1.1.2 telnets to 170.1.1.1, and the new NAT table entry appears, using the same 200.1.1.1 inside global address.

Example 24-5. Example of Reuse of a Dynamic Inside Global IP Address

[Click here to view code image]

```
! Host 10.1.1.1 current uses inside global 200.1.1.1
NAT# show ip nat translations
Pro Inside global Inside local Outside local Outside global
--- 200.1.1.1 10.1.1.1 --- ---
NAT# clear ip nat translation *

!
! telnet from 10.1.1.2 to 170.1.1.1 happened next; not shown
!
! Now host 10.1.1.2 uses inside global 200.1.1.1

NAT# show ip nat translations
Pro Inside global Inside local Outside local Outside global
--- 200.1.1.1 10.1.1.2 --- ---
!
! Telnet from 10.1.1.1 to 170.1.1.1 happened next; not shown
!
NAT# debug ip nat
IP NAT debugging is on

Oct 20 19:23:03.263: NAT*: s=10.1.1.1->200.1.1.2, d=170.1.1.1 [348]
Oct 20 19:23:03.267: NAT*: s=170.1.1.1, d=200.1.1.1->10.1.1.1 [348]
Oct 20 19:23:03.464: NAT*: s=10.1.1.1->200.1.1.2, d=170.1.1.1 [349]
Oct 20 19:23:03.568: NAT*: s=170.1.1.1, d=200.1.1.1->10.1.1.1 [349]
```

Finally, at the end of Example 24-5, you see that host 10.1.1.1 has telnetted to another host in the Internet, plus the output from the **debug ip nat** command. This **debug** command causes the router to issue a message every time a packet has its address translated for NAT. You generate the output results by entering a few lines from the Telnet connection from 10.1.1.1 to 170.1.1.1. The debug output tells us that host 10.1.1.1 now uses inside global address 200.1.1.2 for this new connection.

NAT Overload (PAT) Configuration

The static and dynamic NAT configuration matter, but the NAT overload (PAT) configuration in this section matters more. This is the feature that saves public IPv4 addresses and prolonged IPv4's life.

NAT overload, as mentioned earlier, allows NAT to support many inside local IP addresses with only one or a few inside global IP addresses. By essentially translating the private IP address and port number to a single inside global address, but with a unique port number, NAT can support many (over 65,000) private hosts with only a single public, global address.

Two variations of PAT configuration exist in IOS. If PAT uses a pool of inside global addresses, the configuration looks exactly like dynamic NAT, except the **ip nat inside source list** global command has an **overload** keyword added to the end. If PAT just needs to use one inside global IP address, PAT can use one of its interface IP addresses. Because NAT can support over 65,000 concurrent flows with a single inside global address, a single public IP address can support an entire organization's NAT needs.

The following statement detail the configuration different between NAT overload and 1:1 NAT when using a NAT pool:

Use the same steps for configuring dynamic NAT, as outlined in the previous section, but include the **overload** keyword at the end of the **ip nat inside source list** global command.

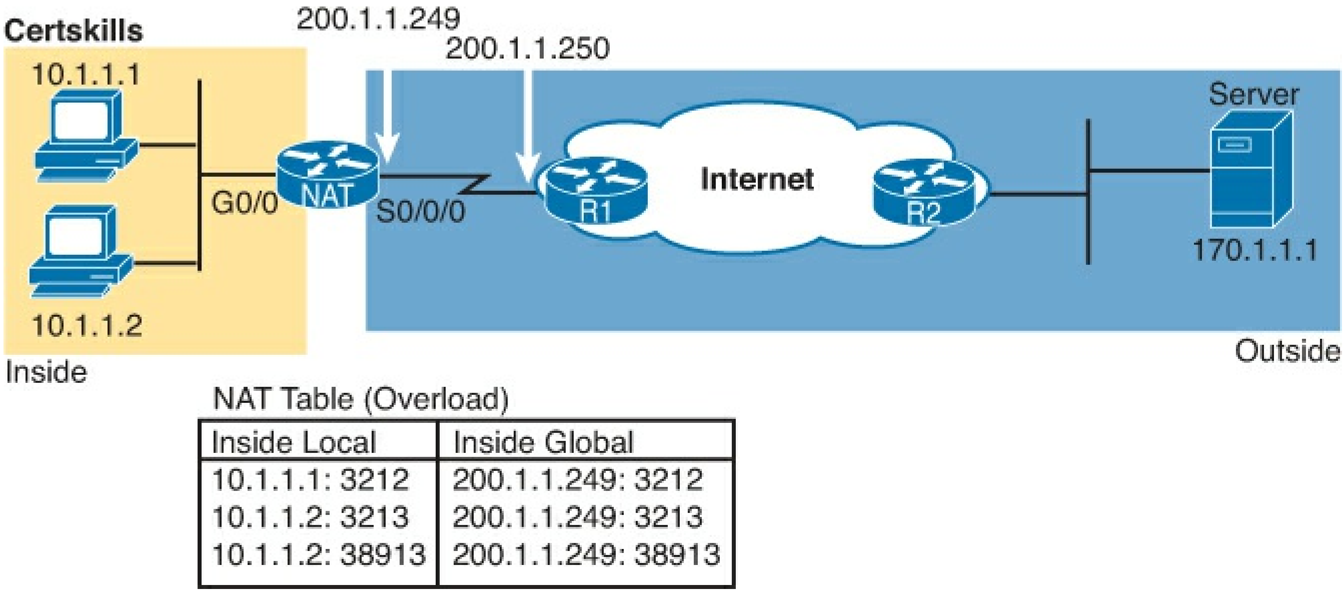
The following checklist details the configuration when using an interface IP address as the sole inside global IP address:

Step 1. As with dynamic and static NAT, configure inside interfaces with the **ip nat inside** interface subcommand.
Step 2. As with dynamic and static NAT, configure outside interfaces with the **ip nat outside** interface subcommand.
Step 3. As with dynamic NAT, configure an ACL that matches the packets entering inside interfaces.

Step 4. Configure the **ip nat inside source list** *acl-number* **interface** *type/number* **overload** global configuration command, referring to the ACL created in Step 3 and to the interface whose IP address will be used for translations.

Example 24-2 shows a dynamic NAT configuration. To convert it to a PAT configuration, the **ip nat inside source list 1 pool fred overload** command would be used instead, simply adding the **overload** keyword.

The next example shows PAT configuration using a single interface IP address. Figure 24-13 shows the same familiar network, with a few changes. In this case, the ISP has given Certskills a subset of network 200.1.1.0: CIDR subnet 200.1.1.248/30. In other words, this subnet has two usable addresses: 200.1.1.249 and 200.1.1.250. These addresses are used on either end of the serial link between Certskills and its ISP. The NAT feature on the Certskills router translates all NAT addresses to its serial IP address, 200.1.1.249.



Inside Local	Inside Global
10.1.1.1: 3212	200.1.1.249: 3212
10.1.1.2: 3213	200.1.1.249: 3213
10.1.1.2: 38913	200.1.1.249: 38913

Figure 24-13. NAT Overload and PAT

In Example 24-6, which shows the NAT overload configuration, NAT translates using inside global address 200.1.1.249 only, so the NAT pool is not required. In the example, host 10.1.1.1 creates two Telnet connections, and host 10.1.1.2 creates one Telnet connection, causing three dynamic NAT entries, each using inside global address 200.1.1.249, but each with a unique port number.

Example 24-6. NAT Overload Configuration

Click here to view code image

```
NAT# show running-config
!
! Lines Omitted for Brevity
!
interface GigabitEthernet0/0
ip address 10.1.1.3 255.255.255.0
ip nat inside
!
interface Serial0/0/0
ip address 200.1.1.249 255.255.255.252
ip nat outside
!
ip nat inside source list 1 interface Serial0/0/0 overload
!
access-list 1 permit 10.1.1.2
access-list 1 permit 10.1.1.1
!

NAT# show ip nat translations
Pro Inside global Inside local Outside local Outside global
tcp 200.1.1.249:3212 10.1.1.1:3212 170.1.1.1:23 170.1.1.1:23
tcp 200.1.1.249:3213 10.1.1.2:3213 170.1.1.1:23 170.1.1.1:23
tcp 200.1.1.249:38913 10.1.1.2:38913 170.1.1.1:23 170.1.1.1:23
NAT# show ip nat statistics
Total active translations: 3 (0 static, 3 dynamic; 3 extended)
Outside interfaces:
Serial0/0/0
Inside interfaces:
```

```
GigabitEthernet0/0
Hits: 103 Misses: 3
Expired translations: 0
Dynamic mappings:
-- Inside Source
access-list 1 interface Serial0/0/0 refcount 3
```

The **ip nat inside source list 1 interface serial 0/0/0 overload** command has several parameters, but if you understand the dynamic NAT configuration, the new parameters shouldn't be too hard to grasp. The **list 1** parameter means the same thing as it does for dynamic NAT: Inside local IP addresses matching ACL 1 have their addresses translated. The **interface serial 0/0/0** parameter means that the only inside global IP address available is the IP address of the NAT router's interface serial 0/0/0. Finally, the **overload** parameter means that overload is enabled. Without this parameter, the router does not perform overload, just dynamic NAT.

As you can see in the output of the **show ip nat translations** command, three translations have been added to the NAT table. Before this command, host 10.1.1.1 creates one Telnet connection to 170.1.1.1, and host 10.1.1.2 creates two Telnet connections. The router creates one NAT table entry for each unique combination of inside local IP address and port.

NAT Troubleshooting

The majority of NAT troubleshooting issues relate to getting the configuration correct. The following list summarizes some hints and tips about how to find the most common NAT configuration problems. Following the list, the text explains one common routing problem that can prevent NAT from working, which relates mainly to ensuring that the configuration is correct.

Key Topic

- Ensure that the configuration includes the **ip nat inside** and **ip nat outside** interface subcommands. These commands enable NAT on the interfaces, and the inside/outside designation is important.
- For static NAT, ensure that the **ip nat inside source static** command lists the inside local address first and the inside global IP address second.
- For dynamic NAT, ensure that the ACL configured to match packets sent by the inside hosts match that host's packets, before any NAT translation has occurred. For example, if an inside local address of 10.1.1.1 should be translated to 200.1.1.1, ensure that the ACL matches source address 10.1.1.1, not 200.1.1.1.
- For dynamic NAT without PAT, ensure that the pool has enough IP addresses. Symptoms of not having enough addresses include a growing value in the second misses counter in the **show ip nat statistics** command output, as well as seeing all the pool addresses already in the NAT table.
- For PAT, it is easy to forget to add the **overload** option on the **ip nat inside source list** command. Without it, NAT works, but PAT does not, often resulting in users' packets not being translated and hosts not being able to get to the Internet.
- Perhaps NAT has been configured correctly, but an ACL exists on one of the interfaces, discarding the packets. Note that IOS processes ACLs before NAT for packets entering an interface, and after translating the addresses for packets exiting an interface.
- Make sure that some user traffic is entering the NAT router on an inside interface, triggering NAT to do a translation. NAT reacts to packets that come in an interface, and then matches the logic referenced in the NAT configuration. The NAT configuration can be perfect, but if no inbound traffic occurs that matches the NAT configuration, NAT does nothing.

Finally, the NAT function on one router can be impacted by a routing problem that occurs on another router. The routers in the outside part of the network, oftentimes the Internet, need to be able to route packets to the inside global IP addresses configured on the NAT router.

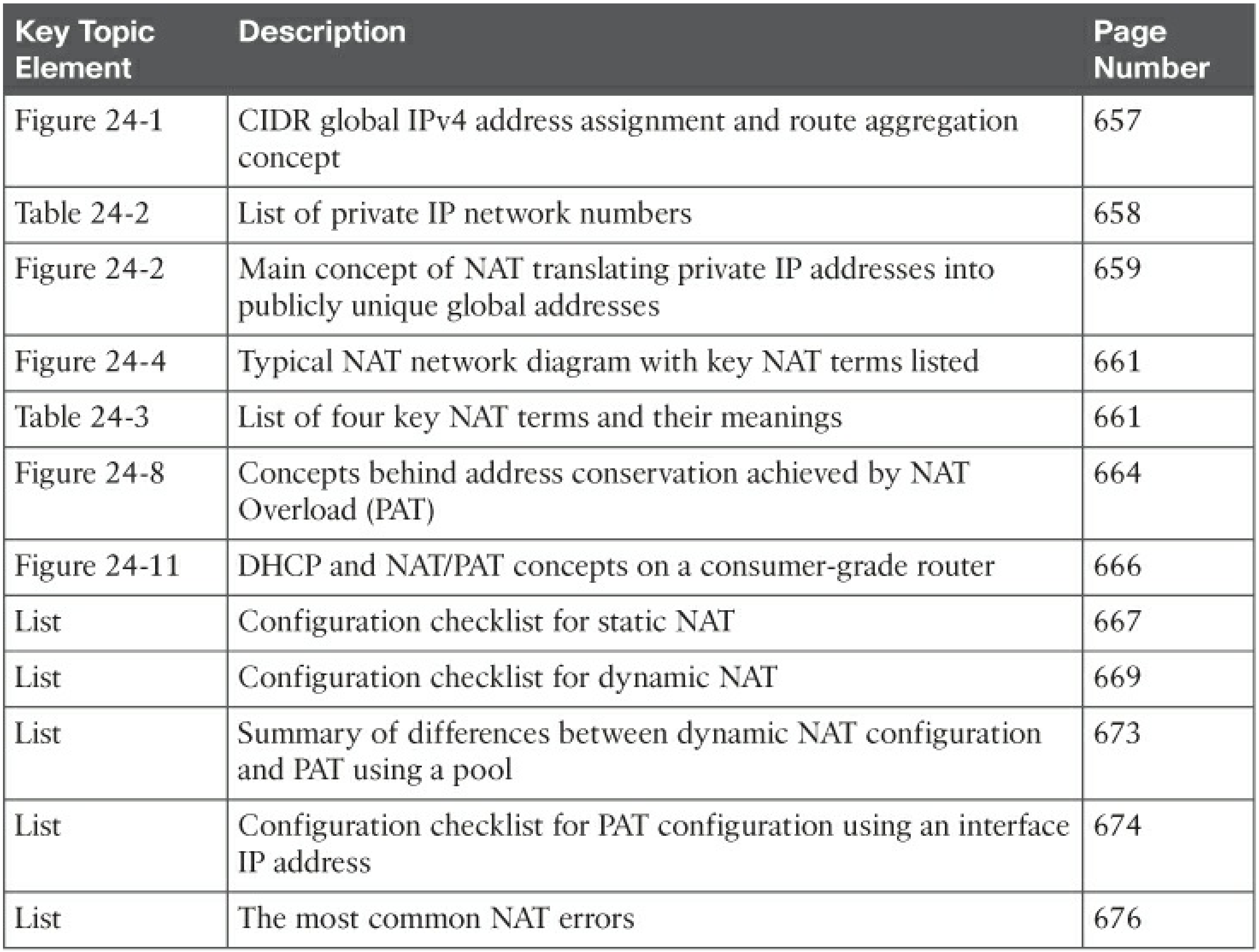
For example, Figure 20-4, earlier in this chapter, shows the flow of packets from inside to outside and outside to inside. Focusing on the outside-to-inside flow, the routers in the Internet needed to know how to route packets to public registered IP address 200.1.1.1. Typically, this address range would be advertised by a dynamic routing protocol. So, if a review of the NAT configuration shows that the configuration looks correct, look at the routes in both the NAT router and other routers to ensure that the routers can forward the packets, based on the addresses used on both sides of the router performing the NAT function.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 24-4 lists these key topics and where each is discussed.

Table 24-4. Key Topics for Chapter 24



Key Topic Element	Description	Page Number
Figure 24-1	CIDR global IPv4 address assignment and route aggregation concept	657
Table 24-2	List of private IP network numbers	658
Figure 24-2	Main concept of NAT translating private IP addresses into publicly unique global addresses	659
Figure 24-4	Typical NAT network diagram with key NAT terms listed	661
Table 24-3	List of four key NAT terms and their meanings	661
Figure 24-8	Concepts behind address conservation achieved by NAT Overload (PAT)	664
Figure 24-11	DHCP and NAT/PAT concepts on a consumer-grade router	666
List	Configuration checklist for static NAT	667
List	Configuration checklist for dynamic NAT	669
List	Summary of differences between dynamic NAT configuration and PAT using a pool	673
List	Configuration checklist for PAT configuration using an interface IP address	674
List	The most common NAT errors	676

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists for you to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

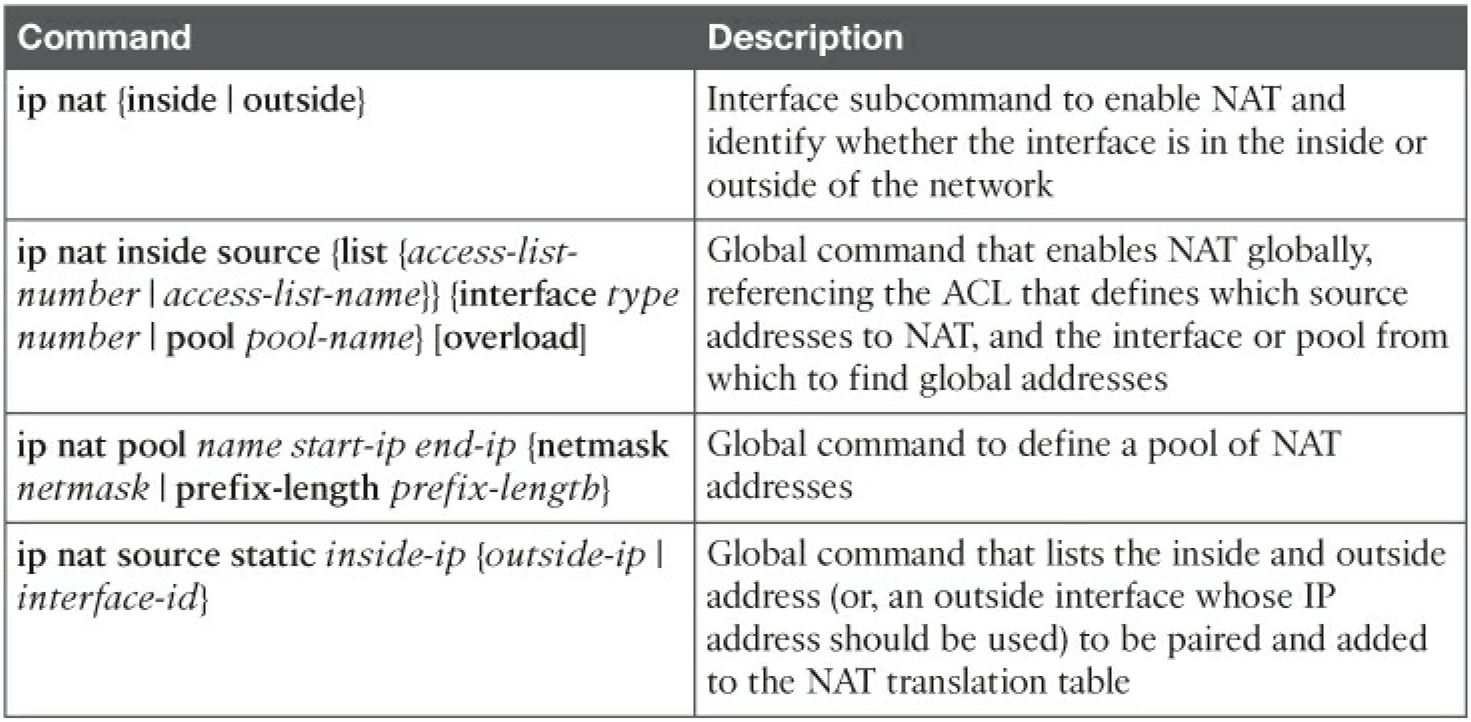
CIDR
inside global
inside local
NAT overload
outside global
outside local

PAT
private IP network

Command Reference to Check Your Memory

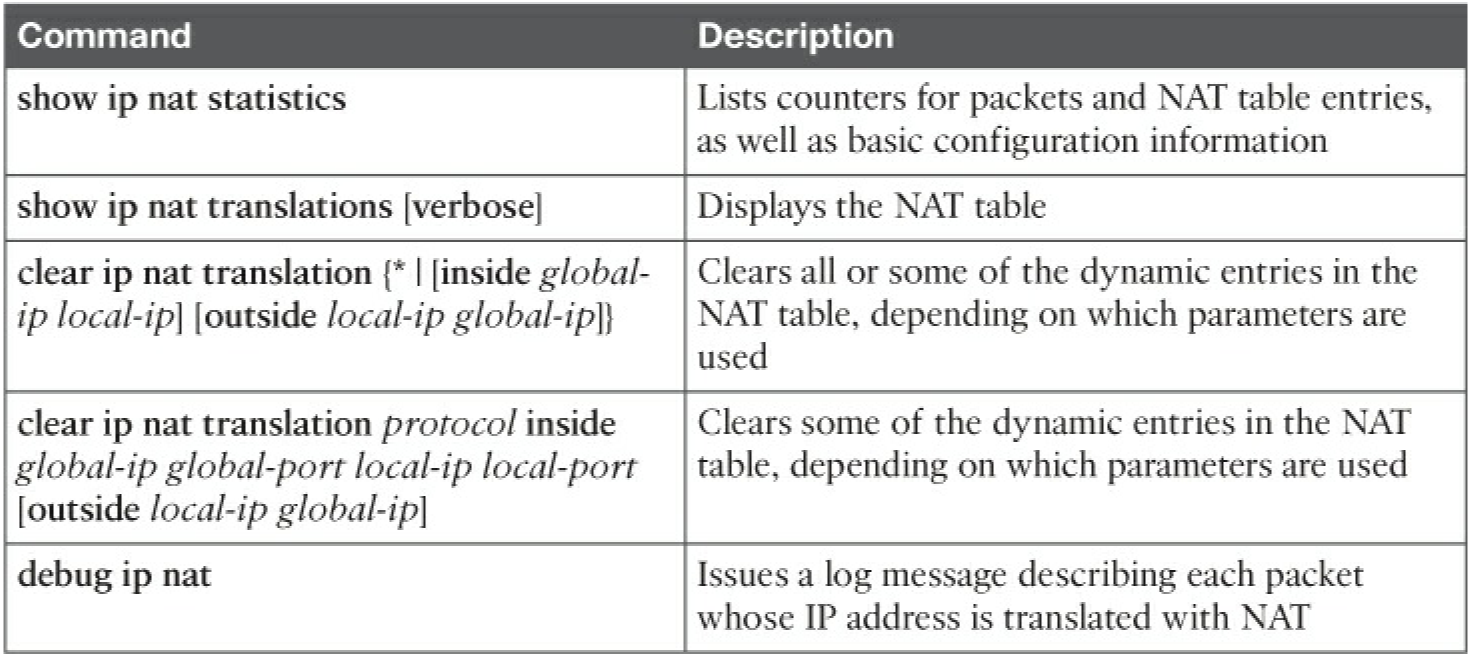
Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To check to see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table with a piece of paper, read the descriptions on the right side, and see whether you remember the command.

Table 24-5. Chapter 24 Configuration Command Reference



Command	Description
ip nat {**inside** | **outside**}	Interface subcommand to enable NAT and identify whether the interface is in the inside or outside of the network
ip nat inside source {**list** {*access-list-number* | *access-list-name*}} {**interface** *type number* | **pool** *pool-name*} [**overload**]	Global command that enables NAT globally, referencing the ACL that defines which source addresses to NAT, and the interface or pool from which to find global addresses
ip nat pool *name start-ip end-ip* {**netmask** *netmask* | **prefix-length** *prefix-length*}	Global command to define a pool of NAT addresses
ip nat source static *inside-ip* {*outside-ip* | *interface-id*}	Global command that lists the inside and outside address (or, an outside interface whose IP address should be used) to be paired and added to the NAT translation table

Table 24-6. Chapter 24 EXEC Command Reference

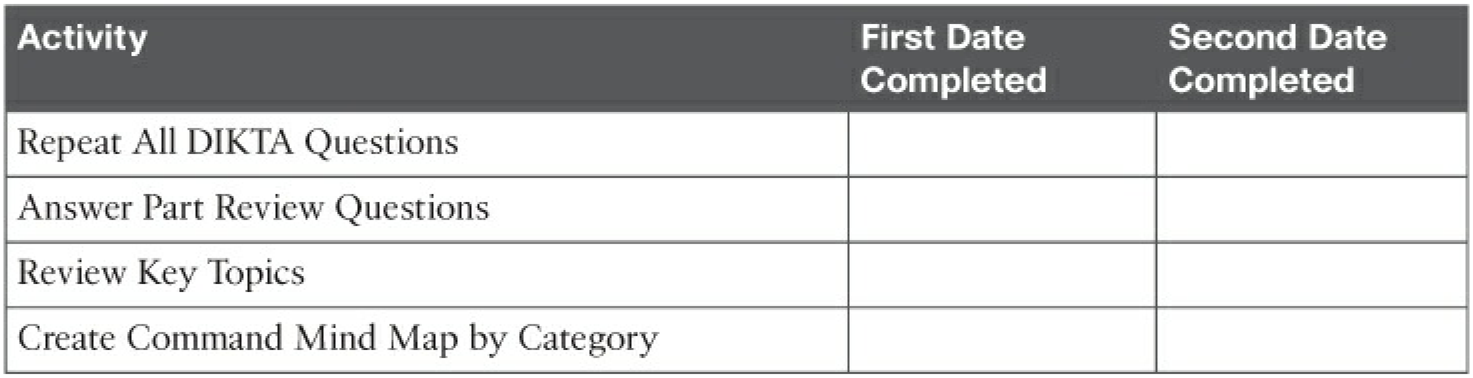


Command	Description
show ip nat statistics	Lists counters for packets and NAT table entries, as well as basic configuration information
show ip nat translations [**verbose**]	Displays the NAT table
clear ip nat translation {***** | [**inside** *global-ip local-ip*] [**outside** *local-ip global-ip*]}	Clears all or some of the dynamic entries in the NAT table, depending on which parameters are used
clear ip nat translation *protocol* **inside** *global-ip global-port local-ip local-port* [**outside** *local-ip global-ip*]	Clears some of the dynamic entries in the NAT table, depending on which parameters are used
debug ip nat	Issues a log message describing each packet whose IP address is translated with NAT

Part VI Review

Keep track of your part review progress with the checklist in Table P6-1. Details on each task follow the table.

Table P6-1. Part VI Part Review Checklist



Activity	First Date Completed	Second Date Completed
Repeat All DIKTA Questions		
Answer Part Review Questions		
Review Key Topics		
Create Command Mind Map by Category		

Repeat All DIKTA Questions

For this task, answer the “Do I Know This Already?” questions again for the chapters in this part of the book, using the PCPT software. Refer to the Introduction to this book, heading “How to View Only DIKTA Questions by Part,” for help with how to make the PCPT software show you DIKTA questions for this part only.

Answer Part Review Questions

For this task, answer the Part Review questions for this part of the book, using the PCPT software. Refer to the Introduction to this book, heading “How to View Only Part Review Questions by Part,” for help with how to make the PCPT software show you Part Review questions for this part only.

Review Key Topics

Key Topic

Browse back through the chapters, and look for the Key Topics icons. If you do not remember some details, take the time to reread those topics.

Create Command Mind Map by Category

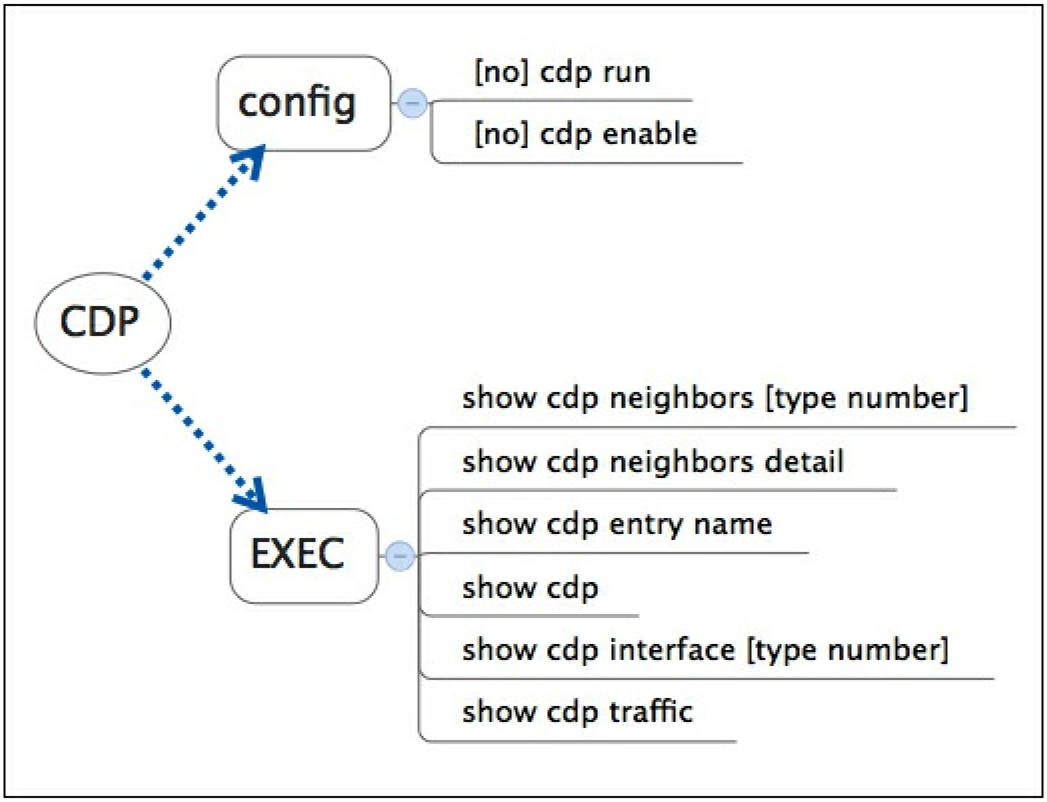
Like Parts II and IV of this book, Part VI introduced more CLI commands. Take a few moments to let your brain sift through what you remember, and what commands your brain thinks go together, so that you can then realize which commands you need to review so that you remember them better.

The goal with this mind map exercise is to help you remember the commands. This exercise does not focus on the details, every single parameter of every command, or even their meaning. The goal is to help you organize the commands internally, so that you know which commands to consider when faced with a real-life problem or an exam question.

Create a mind map with the following categories of commands from this part of the book:

> Numbered standard IPv4 ACLs, numbered extended IPv4 ACLs, named IPv4 ACLs, router and switch security, NAT, and miscellaneous

In this mind map, for each category, think of all configuration commands and all EXEC commands (mostly **show** commands). For each category, group the configuration commands separately from the EXEC commands. Figure P6-1 shows a sample of the organization.



```
[no] cdp run
[no] cdp enable
show cdp neighbors [type number]
show cdp neighbors detail
show cdp entry name
show cdp
show cdp interface [type number]
show cdp traffic
```

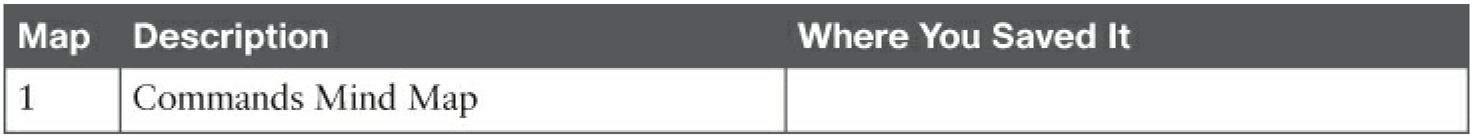
Figure P6-1. Sample Mind Map from the CDP Branch

Finally, keep the following important points in mind when working on this project:

- Do the activity. The learning happens when doing it, not when reading someone else's (or the sample in Appendix O, "Mind Map Solutions"). The point is to map it into your own brain.
- Do this activity without notes and without looking at the book.
- After you finish, review it versus the command summary tables at the ends of the chapters, and note which commands you had originally forgotten.
- Do not worry about every last parameter, or the exact syntax; just write down the first few words of the command.
- For later study, make a note about which commands you feel you truly understand, and which ones about which you feel less confident.
- Repeat this exercise when you have ten spare minutes, as a way to see what you remember (again without your notes).

Appendix O lists a sample mind map answer, but as usual, your mind map can and will look different.

Table P6-2. Configuration Mind Maps for Part VI Review



Map	Description	Where You Saved It
1	Commands Mind Map	

Part VII: IP Version 6

So far, this book has mostly ignored IP version 6 (IPv6). This part reverses the trend, collecting all the specific IPv6 topics into five chapters.

The chapters in this part of the book walk you through the same topics discussed throughout this book for IPv4, oftentimes using IPv4 as a point of comparison. Certainly, many details differ when comparing IPv4 and IPv6. However, many core concepts about IP addressing, subnetting, routing, and routing protocols remain the same. The chapters in this part build on those foundational concepts, adding the specific details about how IPv6 forwards IPv6 packets from one host to another.

Chapter 25: Fundamentals of IP Version 6

Chapter 26: IPv6 Addressing and Subnetting

Chapter 27: Implementing IPv6 Addressing on Routers

Chapter 28: Implementing IPv6 Addressing on Hosts

Chapter 29: Implementing IPv6 Routing

Part VII Review

Chapter 25. Fundamentals of IP Version 6

This chapter covers the following exam topics:

- **Operation of IP Data Networks**
  - Predict the data flow between two hosts across a network.
- **IP addressing (IPv4 / IPv6)**
  - Identify the appropriate IPv6 addressing scheme to satisfy addressing requirements in a LAN/WAN environment.
  - Describe IPv6 addresses
    - Global unicast
- **IP Routing Technologies**
  - Differentiate methods of routing and routing protocols
    - next hop
    - ip routing table
- **Troubleshooting**
  - Troubleshoot and correct common problems associated with IP addressing and host configurations.

IPv4 has been a solid and highly useful part of the growth of TCP/IP and the Internet. For most of the long history of the Internet, and for most corporate networks that use TCP/IP, IPv4 is the core protocol that defines addressing and routing. However, even though IPv4 has many great qualities, it does have some shortcomings, creating the need for a replacement protocol: IP version 6 (IPv6).

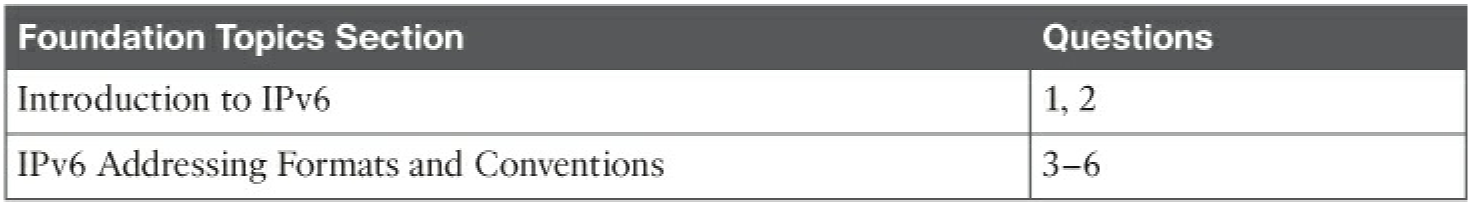
IPv6 defines the same general functions as IPv4, but with different methods of implementing those functions. For example, both IPv4 and IPv6 define addressing, the concepts of subnetting larger groups of addresses into smaller groups, headers used to create an IPv4 or IPv6 packet, and the rules for routing those packets. At the same time, IPv6 handles the details differently, for example, using a 128-bit IPv6 address rather than the 32-bit IPv4 address.

This chapter focuses on the core network layer functions of addressing and routing. The first section of this chapter looks at the big concepts, while the second section looks at the specifics of how to write and type IPv6 addresses.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 25-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Introduction to IPv6	1, 2
IPv6 Addressing Formats and Conventions	3–6

1. Which of the following was a short-term solution to the IPv4 address exhaustion problem?
   - **a.** IP version 6
   - **b.** IP version 5
   - **c.** NAT/PAT
   - **d.** ARP
2. A router receives an Ethernet frame that holds an IPv6 packet. The router then makes a decision to route the packet out a serial link. Which of the following statements is true about how a router forwards an IPv6 packet?
   - **a.** The router discards the Ethernet data link header and trailer of the received frame.
   - **b.** The router makes the forwarding decision based on the packet's source IPv6 address.
   - **c.** The router keeps the Ethernet header, encapsulating the entire frame inside a new IPv6 packet before sending it over the serial link.
   - **d.** The router uses the IPv4 routing table when choosing where to forward the packet.
3. Which of the following is the shortest valid abbreviation for FE80:0000:0000:0100:0000:0000:0000:0123?
   - **a.** FE80::100::123
   - **b.** FE8::1::123
   - **c.** FE80::100:0:0:0:123:4567
   - **d.** FE80:0:0:100::123
4. Which of the following is the shortest valid abbreviation for 2000:0300:0040:0005:6000:0700:0080:0009?

   - **a.** 2:3:4:5:6:7:8:9
   - **b.** 2000:300:40:5:6000:700:80:9
   - **c.** 2000:300:4:5:6000:700:8:9
   - **d.** 2000:3:4:5:6:7:8:9

5. Which of the following is the unabbreviated version of IPv6 address 2001:DB8::200:28?
   - **a.** 2001:0DB8:0000:0000:0000:0000:0200:0028
   - **b.** 2001:0DB8::0200:0028
   - **c.** 2001:0DB8:0:0:0:0:0200:0028
   - **d.** 2001:0DB8:0000:0000:0000:0000:200:0028
6. Which of the following is the prefix for address 2000:0000:0000:0005:6000:0700:0080:0009, assuming a mask of /64?
   - **a.** 2000::5::/64
   - **b.** 2000::5:0:0:0:0/64
   - **c.** 2000:0:0:5::/64
   - **d.** 2000:0:0:5:0:0:0:0/64

Answers to the "Do I Know This Already?" quiz:

1 C **2** A **3** D **4** B **5** A **6** C

Foundation Topics

Introduction to IPv6

IP version 6 (IPv6) serves as the replacement protocol for IP version 4 (IPv4).

Unfortunately, that one bold statement creates more questions than it answers. Why does IPv4 need to be replaced? If IPv4 needs to be replaced, when will that happen—and will it happen quickly? What exactly happens when a company or the Internet replaces IPv4 with IPv6? And the list goes on.

While this introductory chapter cannot get into every detail of why IPv4 needs to eventually be replaced by IPv6, the clearest and most obvious reason for migrating TCP/IP networks to use IPv6 is growth. IPv4 uses a 32-bit address, which totals to a few billion addresses. Interestingly, that seemingly large number of addresses is too small. IPv6 increases the number of addresses to a 128-bit address. For perspective, IPv6 supplies over 10,000,000,000,000,000,000,000,000,000 times as many addresses as IPv4.

The fact that IPv6 uses a different size address field, with some different addressing rules, means that many other protocols and functions change as well. For example, IPv4 routing—in other words, the packet-forwarding process—relies on an understanding of IPv4 addresses. To support IPv6 routing, routers must understanding IPv6 addresses and routing. To dynamically learn routes for IPv6 subnets, routing protocols must support these different IPv6 addressing rules, including rules about how IPv6 creates subnets. As a result, the migration from IPv4 to IPv6 is much more than changing one protocol (IP), but it impacts many protocols.

This first section of the chapter discusses some of the reasons for the change from IPv4 to IPv6, along with the protocols that must change as a result.

The Historical Reasons for IPv6

In the last 40 years, the Internet has gone from its infancy to being a huge influence in the world. It first grew through research at universities, from the ARPANET beginnings of the Internet in the late 1960s into the 1970s. The Internet kept growing fast in the 1980s, with the Internet's fast growth still primarily driven by research and the universities that joined in that research. By the early 1990s, the Internet began to transform to allow commerce, allowing people to sell services and products over the Internet, which drove yet another steep spike upward in the growth of the Internet. Figure 25-1 shows some of these major milestones.

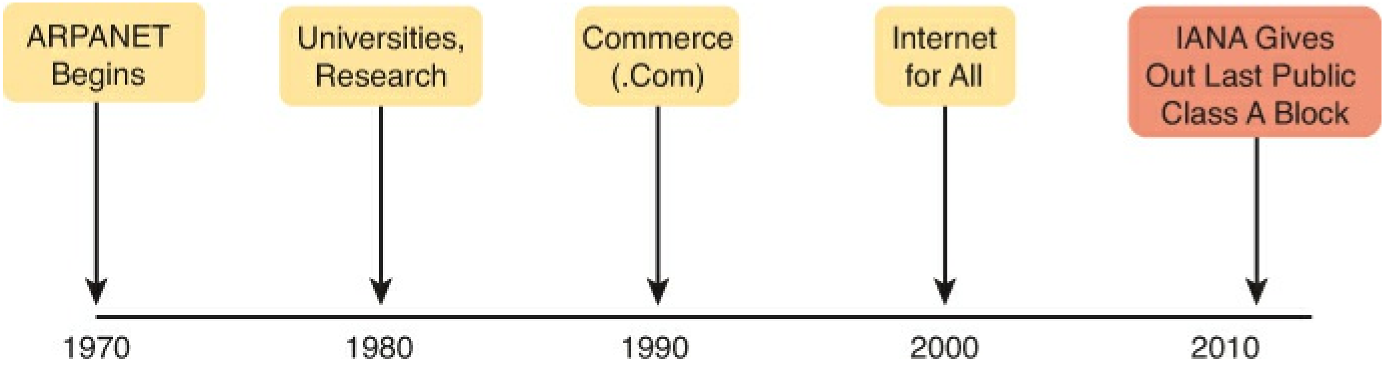


Figure 25-1. Some Major Events in the Growth of the Internet

Note that the figure ends the timeline with an event in which IANA/ICANN, the groups that assign public IPv4 addresses, gave out the last public IPv4 address blocks. IANA/ICANN assigned the final Class A networks to each the Regional Internet Registries (RIR) in February 2011. This event was an important event for the Internet, bringing us closer to the day when a company simply cannot get new IPv4 public address blocks.

In other words, one day, a company could want to connect to the Internet, but it cannot, just because IPv4 has no public addresses left.

Even though the press made a big deal about running out of IPv4 addresses in 2011, those who care about the Internet knew about this potential problem since the late 1980s. The problem, generally called the *IPv4 address exhaustion* problem, could literally have caused the huge growth of the Internet in the 1990s to have come to a screeching halt! Something had to be done.

The IETF came up with several short-term solutions to make IPv4 last longer, hoping to put off the day when the world ran out of public IPv4 addresses. The two primary short-term solutions were Network Address Translation / Port Address Translation (NAT/PAT) and classless interdomain routing (CIDR). Both worked wonderfully. At the time, the Internet community hoped to extend the life of IPv4 for a few more years. In practice, these tools help extend IPv4's life another couple of decades, as seen in the timeline of Figure 25-2.

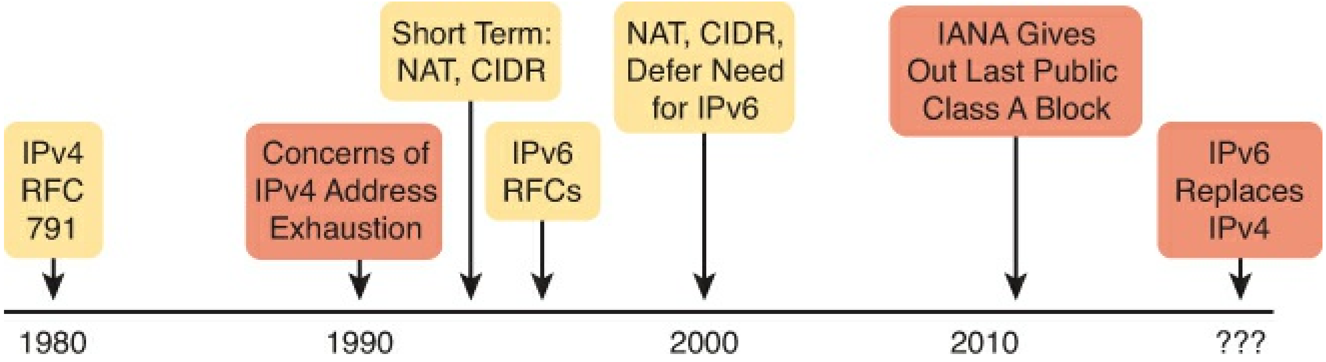

IPv4 RFC 791
Concerns of IPv4 Address Exhaustion
Short Term: NAT, CIDR
IPv6 RFCs
NAT, CIDR, Defer Need for IPv6
IANA Gives Out Last Public Class A Block
IPv6 Replaces IPv4
1980
1990
2000
2010
???

Figure 25-2. Timeline for IPv4 Address Exhaustion and Short-/Long-Term Solutions

Note

The website www.potaroo.net, by Geoff Huston, shows many interesting statistics about the growth of the Internet, including IPv4 address exhaustion.

While the short-term solutions to IPv4 address exhaustion problem gave us all a few more decades to use IPv4, IPv6 gives the world a long-term solution to the problem. IPv6 replaces IPv4 as the core Layer 3 protocol, with a new IPv6 header and new IPv6 addresses. The address size supports a huge number of addresses, solving the address shortage problem for generations (we hope).

The rest of this first section examines IPv6, comparing it to IPv4, focusing on the common features of the two protocols. In particular, this section compares the protocols (including addresses), routing, routing protocols, and miscellaneous other related topics.

Note

You might wonder why the next version of IP is not called IP version 5. There was an earlier effort to create a new version of IP, and it was numbered version 5. IPv5 did not progress to the standards stage. However, to prevent any issues, because version 5 had been used in some documents, the next effort to update IP was numbered as version 6.

The IPv6 Protocols

The primary purpose of the core IPv6 protocol mirrors the same purpose of the IPv4 protocol. That core IPv6 protocol, as defined in RFC 2460, defines a packet concept, addresses for those packets, and the role of hosts and routers. These rules allow the devices to forward packets sourced by hosts, through multiple routers, so that they arrive at the correct destination host. (IPv4 defines those same concepts for IPv4 back in RFC 791.)

However, because IPv6 impacts so many other functions in a TCP/IP network, many more RFCs must define details of IPv6. Some other RFCs define how to migrate from IPv4 to IPv6. Others define new versions of familiar protocols, or replace old protocols with new ones. For example:

Older OSPF Version 2 Upgraded to OSPF Version 3: The older OSPF version 2 works for IPv4, but not for IPv6, so a newer version, OSPF version 3, was created to support IPv6.

ICMP Upgraded to ICMP Version 6: Internet Control Message Protocol (ICMP) worked well with IPv4, but needed to be changed to support IPv6. The new name is ICMPv6.

ARP Replaced by Neighbor Discovery Protocol: For IPv4, Address Resolution Protocol (ARP) discovers the MAC address used by neighbors. IPv6 replaces ARP with a more general Neighbor Discovery Protocol (NDP).

Note

But if you go to any website that lists the RFCs, like www.rfc-editor.org, you can find almost 300 RFCs that have IPv6 in the title.

While the term IPv6, when used broadly, includes many protocols, the one specific protocol called IPv6 defines the new 128-bit IPv6 address. Of course, writing these addresses in binary would be a problem—they probably would not even fit on the width of a piece of paper! IPv6 defines a shorter hexadecimal format, requiring at most 32 hexadecimal digits (one hex digit per 4 bits), with methods to abbreviate the hexadecimal addresses as well.

For example, all of the following are IPv6 addresses, each with 32 or less hex digits.

2345:1111:2222:3333:4444:5555:6666:AAAA
2000:1:2:3:4:5:6:A
FE80::1

The upcoming section "IPv6 Addressing Formats and Conventions" discusses the specifics of how to represent IPv6 addresses, including how to legally abbreviate the hex address values.

Like IPv4, IPv6 defines a header, with places to hold both the source and destination address fields. Compared to IPv4, the IPv6 header does make some other changes besides simply making the address fields larger. However, even though the IPv6 header is larger than an IPv4 header, the IPv6 header is actually simpler (on purpose), to reduce the work done each time a router must route an IPv6 packet. Figure 25-3 shows the required 40-byte part of the IPv6 header.

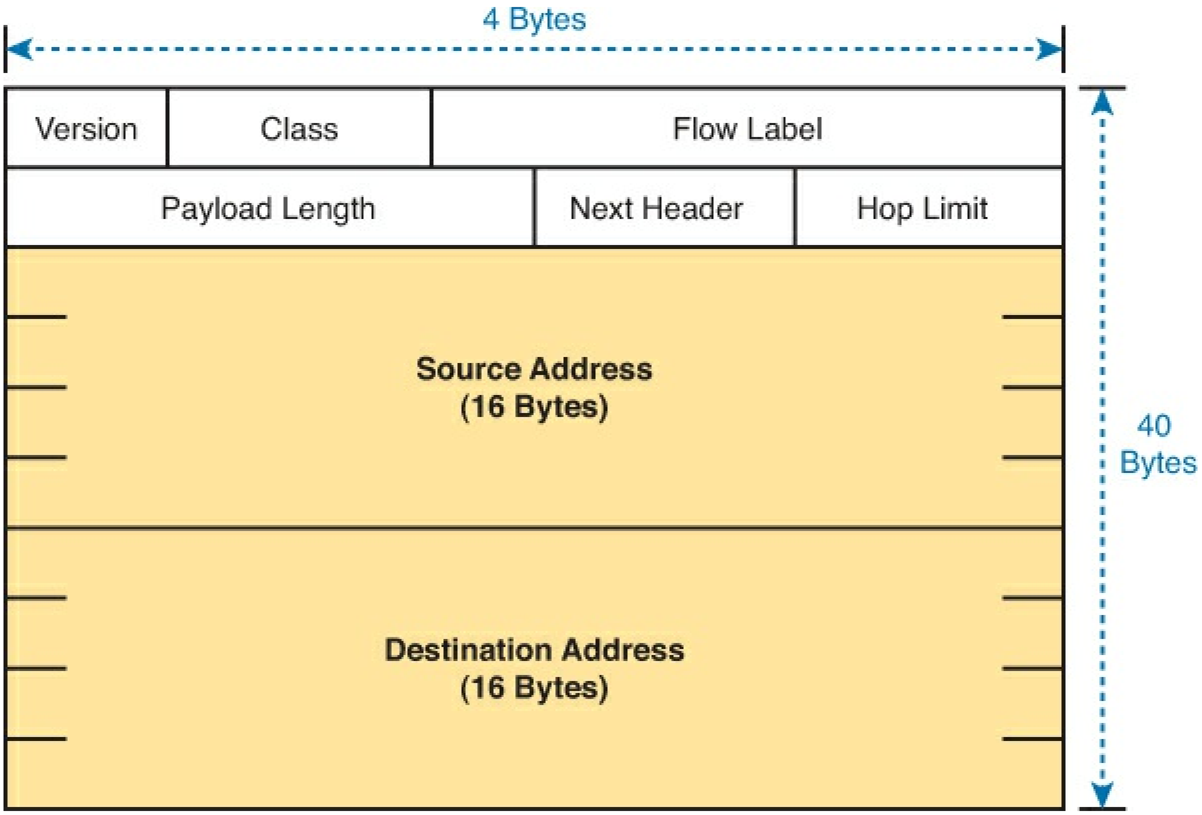


Figure 25-3. IPv6 Header

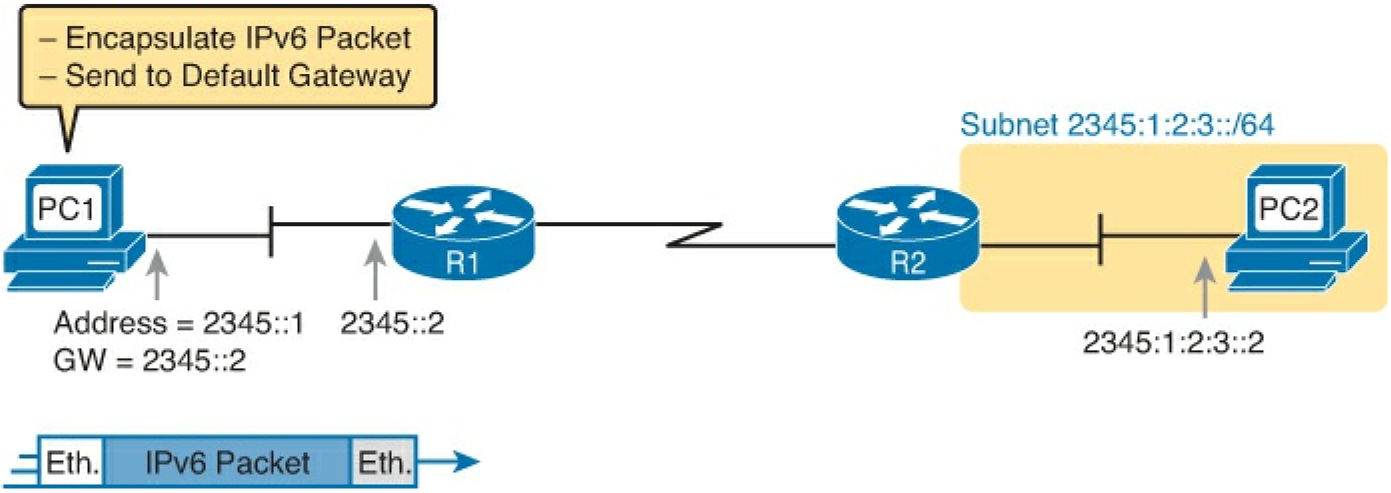
IPv6 Routing

As with many functions of IPv6, IPv6 routing looks just like IPv4 routing from a general perspective, with the differences being clear only once you look at the specifics. Keeping the discussion general for now, IPv6 uses these ideas the same way as IPv4:

- To be able to build and send IPv6 packets out an interface, end-user devices need an IPv6 address on that interface.
- End-user hosts need to know the IPv6 address of a default router, to which the host sends IPv6 packets if the host is in a different subnet.
- IPv6 routers deencapsulate and reencapsulate each IPv6 packet when routing the packet.
- IPv6 routers make routing decisions by comparing the IPv6 packet's destination address to the router's IPv6 routing table; the matched route list directions of where to send the IPv6 packet next.

> **Note**
>
> You could take the preceding list, and replace every instance of IPv6 with IPv4, and all the statements would be true of IPv4 as well.

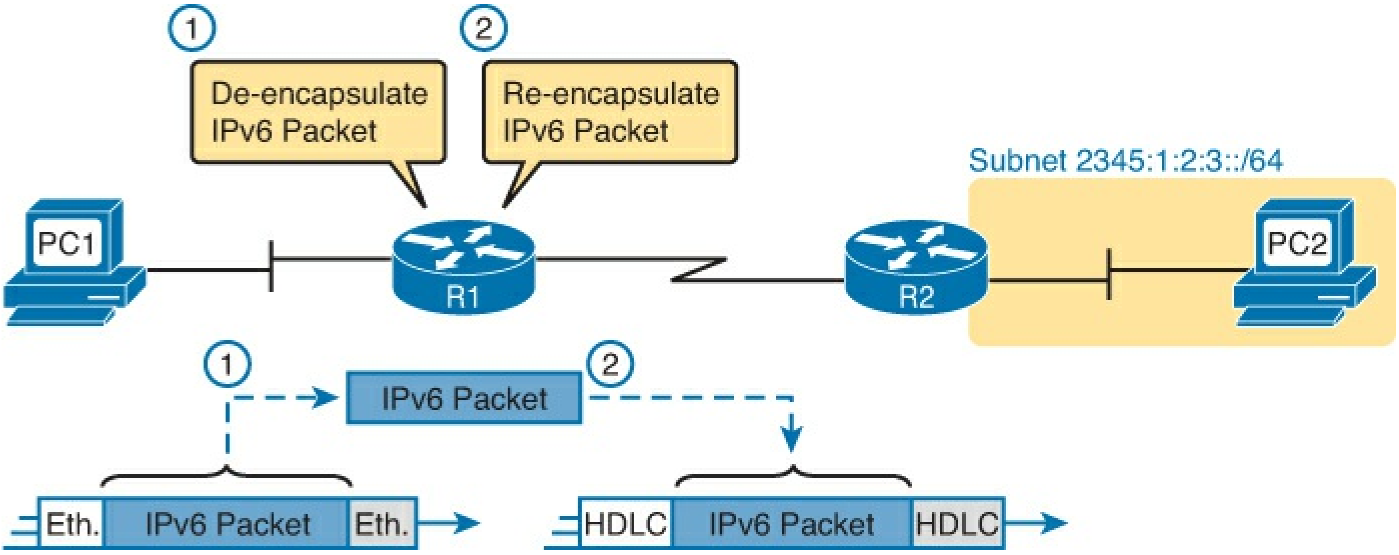
While the list shows some concepts that should be familiar from IPv4, the next few figures show the concepts with an example. First, Figure 25-4 shows a few settings on a host. The host (PC1) has an address of 2345::1. PC1 also knows its default gateway of 2345::2. (Both values are valid abbreviations for real IPv6 addresses.) To send an IPv6 packet to host PC2, on another IPv6 subnet, PC1 creates an IPv6 packet and sends it to R1, PC1's default gateway.



– Encapsulate IPv6 Packet
– Send to Default Gateway
Subnet 2345:1:2:3::/64
PC1
R1
R2
PC2
Address = 2345::1
GW = 2345::2
2345::2
2345:1:2:3::2
Eth.
IPv6 Packet
Eth.

Figure 25-4. IPv6 Host Building and Sending an IPv6 Packet

The router (R1) has many small tasks to do when forwarding this IPv6 packet, but for now, focus on the work R1 does related to encapsulation. As seen in Step 1 of Figure 25-5, R1 receives the incoming data link frame, and extracts (deencapsulates) the IPv6 packet from inside the frame, discarding the original data link header and trailer. At Step 2, once R1 knows to forward the IPv6 packet to R2, R1 adds a correct outgoing data link header and trailer to the IPv6 packet, encapsulating the IPv6 packet.



①
②
De-encapsulate IPv6 Packet
Re-encapsulate IPv6 Packet
Subnet 2345:1:2:3::/64
PC1
R1
R2
PC2
①
IPv6 Packet
②
Eth.
IPv6 Packet
Eth.
HDLC
IPv6 Packet
HDLC

Figure 25-5. IPv6 Router Performing Routine Encapsulation Tasks When Routing IPv6

When a router like R1 deencapsulates the packet from the data link frame, it must also decide what type of packet sits inside the frame. To do so, the router must look at a protocol type field in the data link header, which identifies the type of packet inside the data link frame. Today, most data link frames carry either an IPv4 packet or an IPv6 packet.

To route an IPv6 packet, a router must use its IPv6 routing table instead of the IPv4 routing table. The router must look at the packet's destination IPv6 address and compare that address to the router's current IPv6 routing table. The router uses the forwarding instructions in the matched IPv6 route to forward the IPv6 packet. Figure 25-6 shows the overall process.

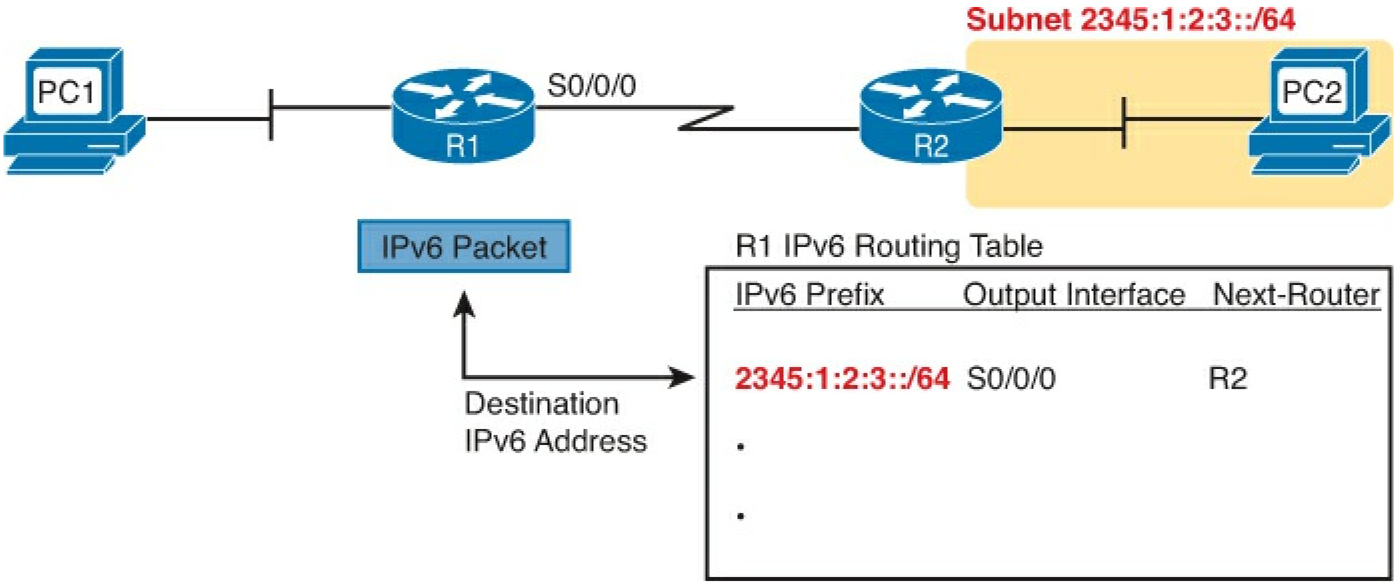


Figure 25-6. IPv6 Router Performing Routine Encapsulation Tasks When Routing IPv6

Note that again, the process works like IPv4, except that the IPv6 packet lists IPv6 addresses, and the IPv6 routing table lists routing information for IPv6 subnets (called prefixes).

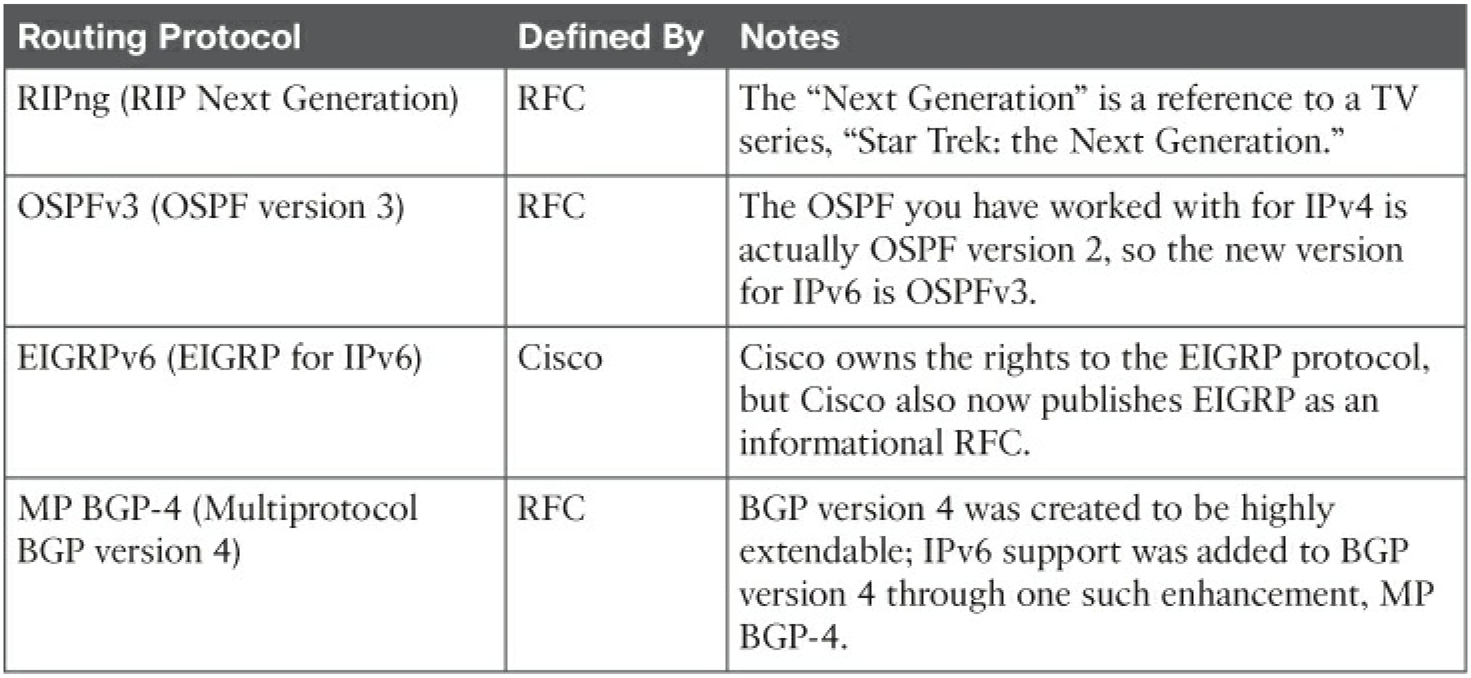
Finally, in most enterprise networks, the routers will route both IPv4 and IPv6 packets at the same time. That is, your company will not decide to adopt IPv6, and then late one weekend night turn off all IPv4 and enable IPv6 on every device. Instead, IPv6 allows for a slow migration, during which some or all routers forward both IPv4 and IPv6 packets. (The migration strategy of running both IPv4 and IPv6 is called *dual stack*.) All you have to do is configure the router to route IPv6 packets, in addition to the existing configuration for routing IPv4 packets.

IPv6 Routing Protocols

IPv6 routers need to learn routes for all the possible IPv6 prefixes (subnets). Just like with IPv4, IPv6 routers use routing protocols, with familiar names, and generally speaking, with familiar functions.

None of the IPv4 routing protocols could be used to advertise IPv6 routes originally. They all required some kind of update to add messages, protocols, and rules to support IPv6. Over time, Routing Information Protocol (RIP), Open Shortest Path First (OSPF), Enhanced Interior Gateway Routing Protocol (EIGRP), and Border Gateway Protocol (BGP) were all updated to support IPv6. Table 25-2 lists the names of these routing protocols, with a few comments.

Table 25-2. IPv6 Routing Protocols



Routing Protocol	Defined By	Notes
RIPng (RIP Next Generation)	RFC	The "Next Generation" is a reference to a TV series, "Star Trek: the Next Generation."
OSPFv3 (OSPF version 3)	RFC	The OSPF you have worked with for IPv4 is actually OSPF version 2, so the new version for IPv6 is OSPFv3.
EIGRPv6 (EIGRP for IPv6)	Cisco	Cisco owns the rights to the EIGRP protocol, but Cisco also now publishes EIGRP as an informational RFC.
MP BGP-4 (Multiprotocol BGP version 4)	RFC	BGP version 4 was created to be highly extendable; IPv6 support was added to BGP version 4 through one such enhancement, MP BGP-4.

Additionally, these routing protocols also follow the same IGP and EGP conventions as their IPv4 cousins. RIPng, EIGRPv6, and OSPFv3 act as interior gateway protocols, advertising IPv6 routes inside an enterprise.

As you can see from this introduction, IPv6 uses many of the same big ideas as IPv4. Both define headers with a source and destination address. Both define the routing of packets, with the routing process discarding old data link headers and trailers when forwarding the packets. And routers use the same general process to make a routing decision, comparing the packet's destination IP address to the routing table.

The big differences between IPv4 and IPv6 revolve around the bigger IPv6 addresses. The next topic begins the looking at the specifics of these IPv6 addresses.

IPv6 Addressing Formats and Conventions

The CCENT and CCNA R/S exams require some fundamental skills in working with IPv4 addresses. For example, you need to be able to interpret IPv4 addresses, like 172.21.73.14. You need to be able to work with prefix-style masks, like *25, and interpret what that means when used with a particular IPv4 address. And you need to be able to take an address and mask, like 172.21.73.14*25, and find the subnet ID.

This second major section of this chapter discusses these same ideas for IPv6 addresses. In particular, this section looks at

- How to write and interpret unabbreviated 32-digit IPv6 addresses
- How to abbreviate IPv6 addresses, and how to interpret abbreviated addresses
- How to interpret the IPv6 prefix length mask
- How to find the IPv6 prefix (subnet ID), based on an address and prefix length mask

The biggest challenge with these tasks lies in the sheer size of the numbers. Thankfully, the math to find the subnet ID—often a challenge for IPv4—is easier for IPv6, at least to the depth discussed in this book.

Representing Full (Unabbreviated) IPv6 Addresses

IPv6 uses a convenient hexadecimal (hex) format for addresses. To make it more readable, IPv6 uses a format with eight sets of four hex digits, with each set of four digits separated by a colon. For example:

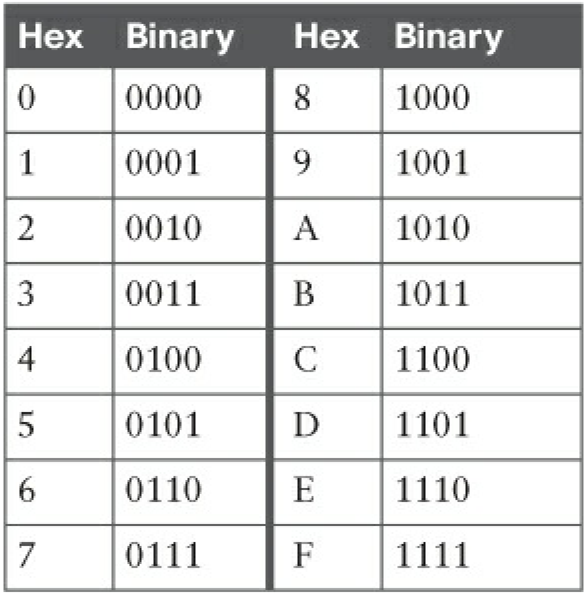
2340:1111:AAAA:0001:1234:5678:9ABC:1234

Note

For convenience, the author uses the term *quartet* for one set of four hex digits, with eight quartets in each IPv6 address. Note that the IPv6 RFCs do not use the term *quartet*.

IPv6 addresses also have a binary format as well, but thankfully, most of the time you do not need to look at the binary version of the addresses. However, in those cases, converting from hex to binary is relatively easy. Just change each hex digit to the equivalent 4-bit value listed in Table 25-3.

Table 25-3. Hexadecimal/Binary Conversion Chart



Hex	Binary	Hex	Binary
0	0000	8	1000
1	0001	9	1001
2	0010	A	1010
3	0011	B	1011
4	0100	C	1100
5	0101	D	1101
6	0110	E	1110
7	0111	F	1111

Abbreviating and Expanding IPv6 Addresses

IPv6 also defines ways to abbreviate or shorten how you write or type an IPv6 address. Why? Although using a 32-digit hex number works much better than working with a 128-bit binary number, 32 hex digits is still a lot of digits to remember, recognize in command output, and type on a command line. The IPv6 address abbreviation rules let you shorten these numbers.

Computers and routers typically use the shortest abbreviation, even if you type all 32 hex digits of the address. So even if you would prefer to use the longer unabbreviated version of the IPv6 address, you need to be ready to interpret the meaning of an abbreviated IPv6 address as listed by a router or host. This section first looks at abbreviating addresses, and then at expanding addresses.

Abbreviating IPv6 Addresses

Two basic rules let you, or any computer, shorten or abbreviate an IPv6 address:

1. Inside each quartet of four hex digits, remove the leading 0s (0s on the left side of the quartet) in the three positions on the left. (Note: at this step, a quartet of 0000 will leave a single 0.)
2. Find any string of two or more consecutive quartets of all hex 0s, and replace that set of quartets with double colon (::). The :: means "two or more quartets of all 0s." However, you can only use :: once in a single address, because otherwise the exact IPv6 might not be clear.

For example, consider the following IPv6 address. The bold digits represent digits in which the address could be abbreviated.

FE00:0000:0000:0001:0000:0000:0000:0056

Applying the first rule, you would look at all eight quartets independently. In each, remove all the leading 0s. Note that five of the quartets have four 0s, so for these, only remove three 0s, leaving the following value:

FE00:0:0:1:0:0:0:56

While this abbreviation is valid, the address can be abbreviated more, using the second rule. In this case, two instances exist where more than one quartet in a row has only a 0. Pick the longest such sequence, and replace it with ::, giving you the shortest legal abbreviation:

FE00:0:0:1::56

While FE00:0:0:1::56 is indeed the shortest abbreviation, this example happens to make it easier to see the two most common mistakes when abbreviating IPv6 addresses. First, never remove trailing 0s in a quartet (0s on the right side of the quartet). In this case, the first quartet of FE00 cannot be shortened at all, because the two 0s trail. So, the following address, that begins now with only FE in the first quartet, is not a correct abbreviation of the original IPv6 address:

FE:0:0:1::56

The second common mistake is to replace all series of all 0 quartets with a double colon. For example, the following abbreviation would be incorrect for the original IPv6 address listed in this topic:

FE00::1::56

The reason this abbreviation is incorrect is because now you do not know how many quartets of all 0s to substitute into each :: to find the original unabbreviated address.

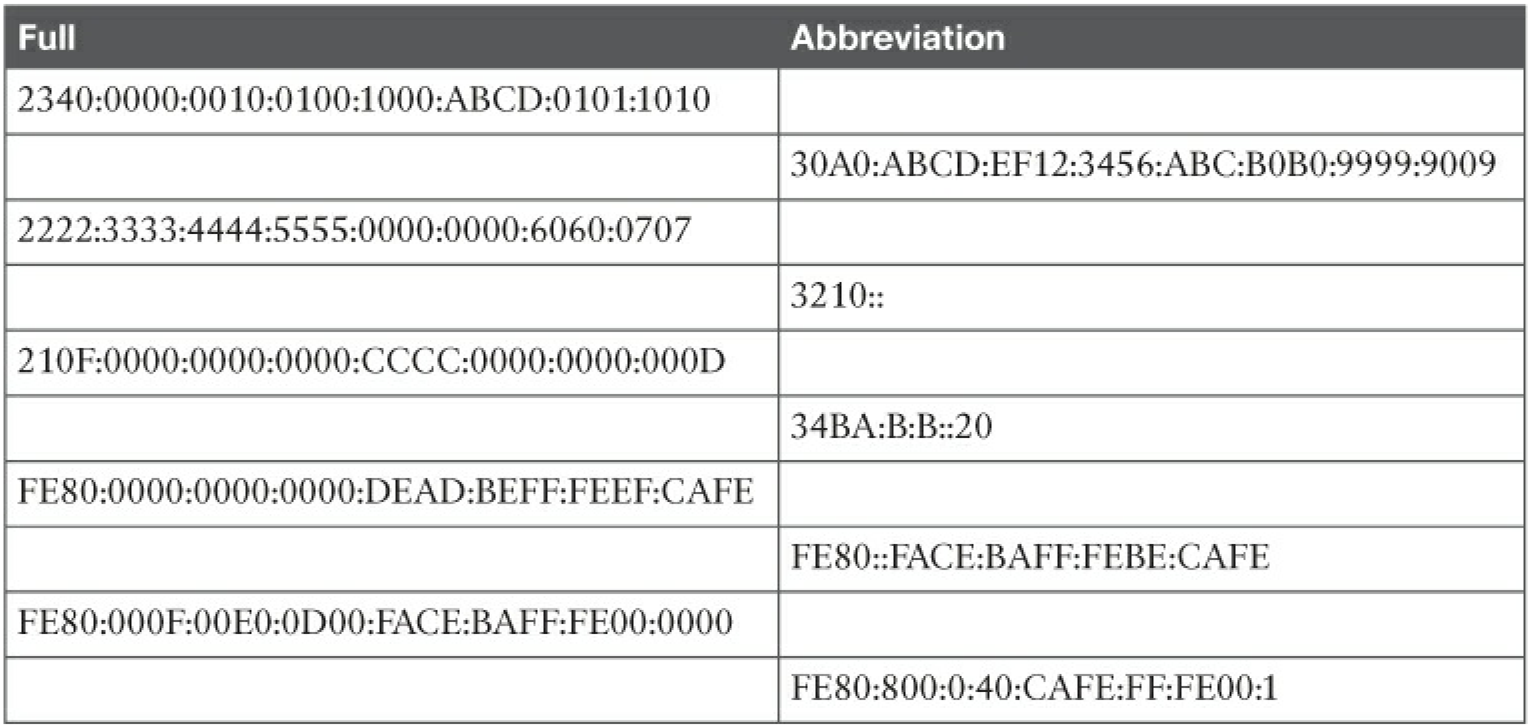
Expanding Abbreviated IPv6 Addresses

To expand an IPv6 address back into its full unabbreviated 32-digit number, use two similar rules. The rules basically reverse the logic of the previous two rules:

1. In each quartet, add leading 0s as needed until the quartet has four hex digits.
2. If a double colon (::) exists, count the quartets currently shown; the total should be less than 8. Replace the :: with multiple quartets of 0000 so that eight total quartets exist.

The best way to get comfortable with these addresses and abbreviations is to do some yourself. Table 25-4 lists some practice problems, with the full 32-digit IPv6 address on the left, and the best abbreviation on the right. The table gives you either the expanded or abbreviated address, and you need to supply the opposite value. The answers sit at the end of the chapter, in the section "Answers to Earlier Practice Problems."

Table 25-4. IPv6 Address Abbreviation and Expansion Practice



Full	Abbreviation
2340:0000:0010:0100:1000:ABCD:0101:1010	
	30A0:ABCD:EF12:3456:ABC:B0B0:9999:9009
2222:3333:4444:5555:0000:0000:6060:0707	
	3210::
210F:0000:0000:0000:CCCC:0000:0000:000D	
	34BA:B:B::20
FE80:0000:0000:0000:DEAD:BEFF:FEEF:CAFE	
	FE80::FACE:BAFF:FEBE:CAFE
FE80:000F:00E0:0D00:FACE:BAFF:FE00:0000	
	FE80:800:0:40:CAFE:FF:FE00:1

You will become more comfortable with these abbreviations as you get more experience. The "Exam Preparation Tasks" section at the end of this chapter lists several suggestions for getting more practice.

Representing the Prefix Length of an Address

IPv6 uses a mask concept, called the *prefix length*, similar to IPv4 subnet masks. Similar to the IPv4 prefix-style mask, the IPv6 prefix length is written as a /, followed by a decimal number. The prefix length defines how many bits of the IPv6 address defines the IPv6 prefix, which is basically the same concept as the IPv4 subnet ID.

When writing IPv6 addresses, if the prefix length matters, the prefix length follows the IPv6 address. When writing documentation, you can leave a space between the address and the /, but when typing the values into a Cisco router, you might need to configure with or without the space. For example, use either of these for an address with a 64-bit prefix length:

2222:1111:0:1:A:B:C:D/64

2222:1111:0:1:A:B:C:D /64

Finally, note that the prefix length is a number of bits, so with IPv6, the legal value range is from 0 through 128, inclusive.

Calculating the IPv6 Prefix (Subnet ID)

With IPv4, you can take an IP address and the associated subnet mask, and calculate the subnet ID. With IPv6 subnetting, you can take an IPv6 address and the associated prefix length, and calculate the IPv6 equivalent of the subnet ID: an *IPv6 prefix*.

Like with different IPv4 subnet masks, some IPv6 prefix lengths make for an easy math problem to find the IPv6 prefix, while some prefix lengths make the math more difficult. This section looks at the easier cases, mainly because the size of the IPv6 address space lets us all choose to use IPv6 prefix lengths that make the math much easier.

Finding the IPv6 Prefix

In IPv6, a prefix represents a group of IPv6 addresses. For now, this section focuses on the math, and only the math, for finding the number that represents that prefix. Chapter 26, "IPv6 Addressing and Subnetting," then starts putting more meaning behind the actual numbers.

Each IPv6 prefix, or subnet if you prefer, has a number that represents the group. Per the IPv6 RFCs, the number itself is also called the prefix, but many people just call it a subnet number or subnet ID, using the same terms as IPv4.

Like IPv4, you can start with an IPv6 address and prefix length, and find the prefix, with the same general rules that you use in IPv4. If the prefix length is /P, use these rules:

Key Topic

1. Copy the first P bits.
2. Change the rest of the bits to 0.

When using a prefix length that happens to be a multiple of 4, you do not have to think in terms of bits, but in terms of hex digits. A prefix length that is a multiple of 4 means that each hex digit is either copied, or changed to 0. Just for completeness, if the prefix length is indeed a multiple of 4, the process becomes

1. Identify the number of hex digits in the prefix by dividing the prefix length (which is in bits) by 4.
2. Copy the hex digits determined to be in the prefix per the first step.
3. Change the rest of the hex digits to 0.

Figure 25-7 shows an example, with a prefix length of 64. In this case, Step 1 looks at the /64 prefix length, and calculates that the prefix has 16 hex digits. Step 2 copies the first 16 digits of the IPv6 address, while Step 3 records hex 0s for the rest of the digits.

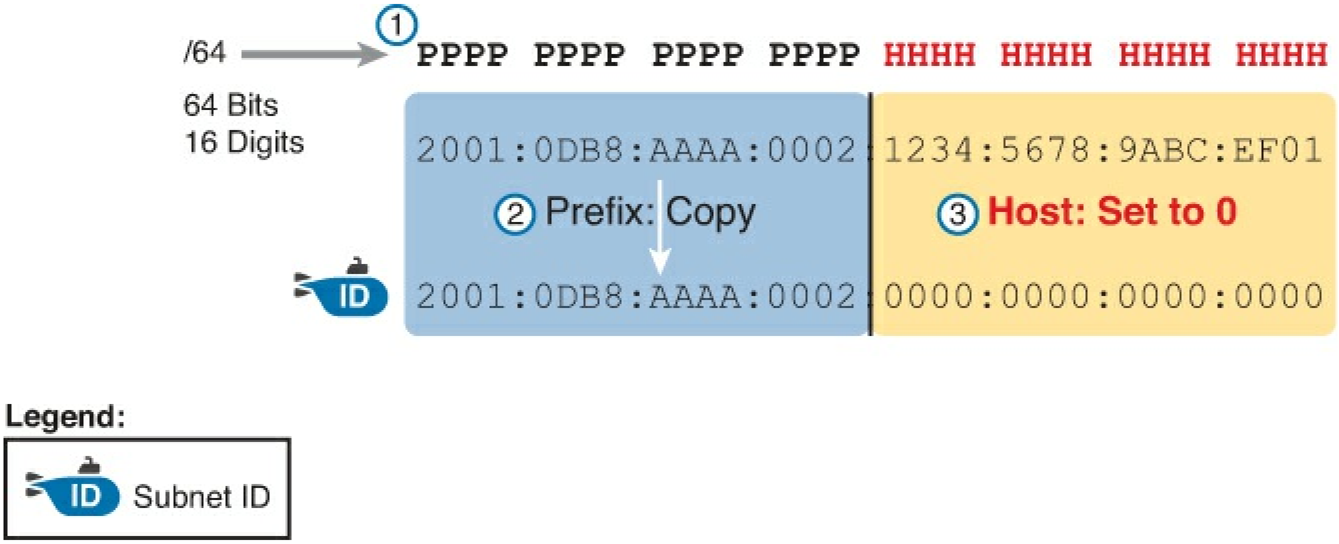

/64
①
PPPP PPPP PPPP PPPP HHHH HHHH HHHH HHHH
64 Bits
16 Digits
2001:0DB8:AAAA:0002:1234:5678:9ABC:EF01
② Prefix: Copy
③ Host: Set to 0
ID
2001:0DB8:AAAA:0002:0000:0000:0000:0000
Legend:
ID Subnet ID

Figure 25-7. Creating the IPv6 Prefix from an Address/Length

After you find the IPv6 prefix, you should also be ready to abbreviate the IPv6 prefix using the same rules you use to abbreviate IPv6 addresses. However, you should pay extra attention to the end of the prefix, because it often has several octets of all 0 values. As a result, the abbreviation typically ends with two colons (::).

For example, consider the following IPv6 address that is assigned to a host on a LAN:

2000:1234:5678:9ABC:1234:5678:9ABC:1111/64

This example shows an IPv6 address that itself cannot be abbreviated. After you calculate the prefix for the subnet in which the address resides, by zeroing out the last 64 bits (16 digits) of the address, you find the following prefix value:

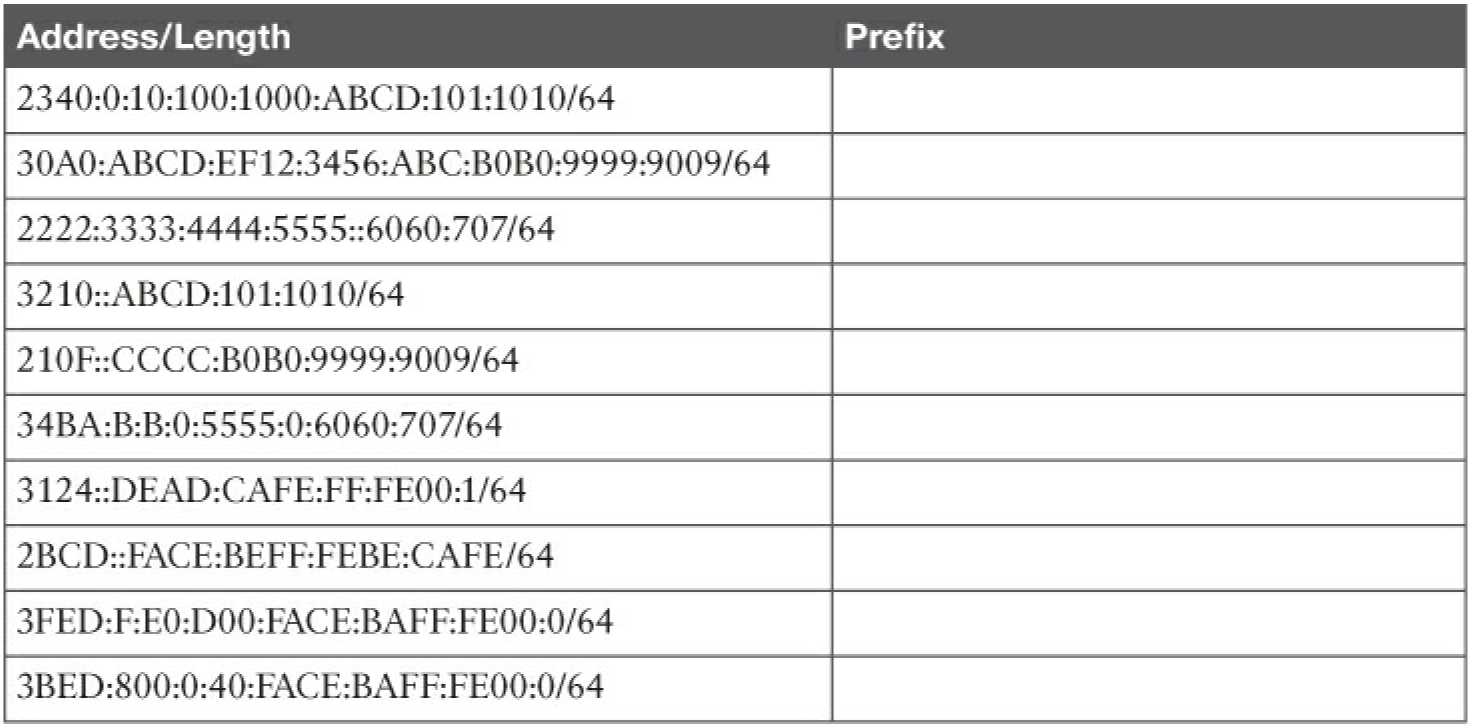
2000:1234:5678:9ABC:**0000:0000:0000:0000**/64

This value can be abbreviated, with four quartets of all 0s at the end, as follows:

2000:1234:5678:9ABC::/64

To get better at the math, take some time to work through finding the prefix for several practice problems, as listed in Table 25-5. The answers sit at the end of the chapter, in the section “Answers to Earlier Practice Problems.”

Table 25-5. Finding the IPv6 Prefix from an Address/Length Value



Address/Length	Prefix
2340:0:10:100:1000:ABCD:101:1010/64	
30A0:ABCD:EF12:3456:ABC:B0B0:9999:9009/64	
2222:3333:4444:5555::6060:707/64	
3210::ABCD:101:1010/64	
210F::CCCC:B0B0:9999:9009/64	
34BA:B:B:0:5555:0:6060:707/64	
3124::DEAD:CAFE:FF:FE00:1/64	
2BCD::FACE:BEFF:FEBE:CAFE/64	
3FED:F:E0:D00:FACE:BAFF:FE00:0/64	
3BED:800:0:40:FACE:BAFF:FE00:0/64	

The "Exam Preparation Tasks" section at the end of this chapter lists several suggestions for getting more practice. The "Answers to Earlier Practice Problems" section at the end of the chapter also contains Table 25-9, which lists a completed version of this table so that you can check your work.

Working with More Difficult IPv6 Prefix Lengths

Some prefix lengths make the math to find the prefix very easy, some mostly easy, and some require you to work in binary. If the prefix length is a multiple of 16, the process of copying part of the address copies entire quartets. If the prefix length is not a multiple of 16, but is a multiple of 4, at least the boundary sits at the edge of a hex digit, so you can avoid working in binary.

Although the /64 prefix length is by far the most common prefix length, you should be ready to find the prefix when using a prefix length that is any multiple of 4. For example, consider the following IPv6 address and prefix length:

2000:1234:5678:9ABC:1234:5678:9ABC:1111/56

Because this example uses a /56 prefix length, the prefix includes the first 56 bits, or first 14 complete hex digits, of the address. The rest of the hex digits will be 0, resulting in the following prefix:

2000:1234:5678:9A**00**:**0000:0000:0000:0000**/56

This value can be abbreviated, with four quartets of all 0s at the end, as follows:

2000:1234:5678:9A**00**::/56

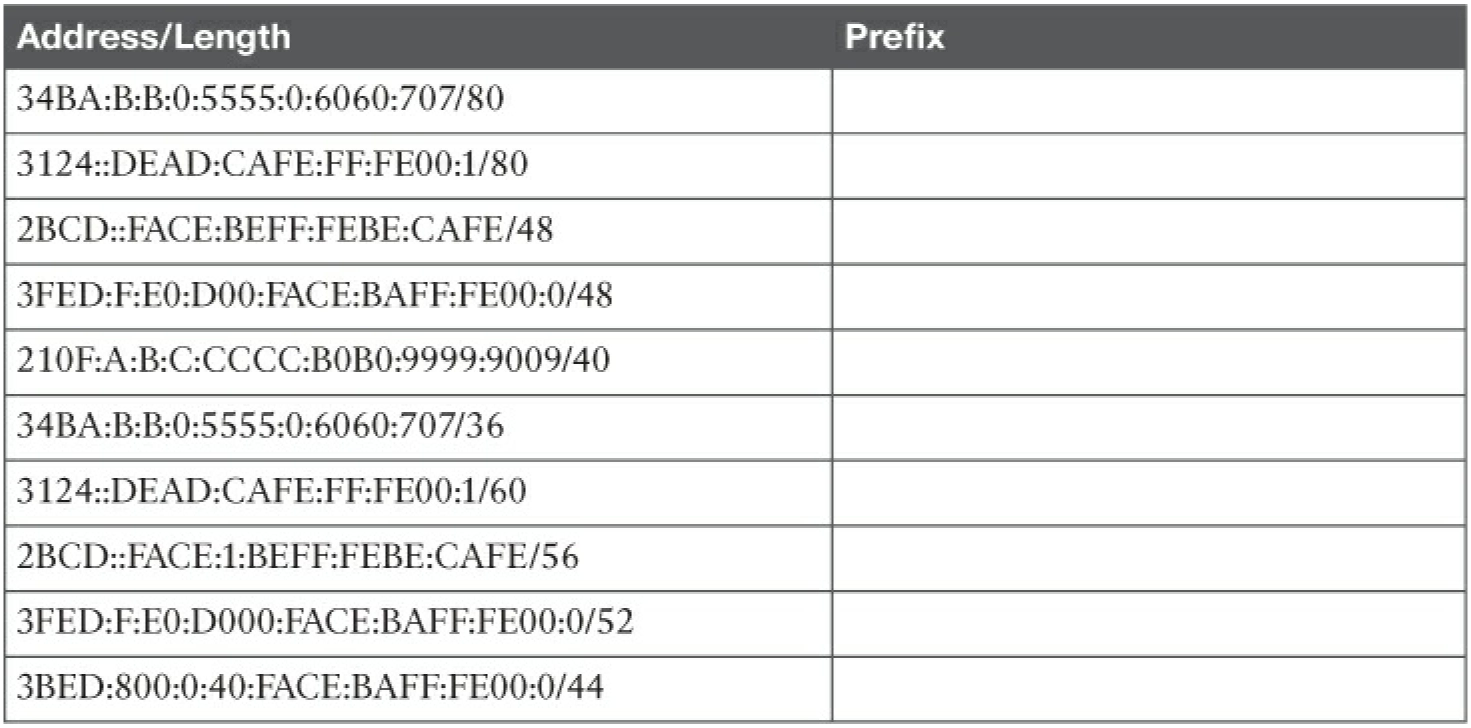
This example shows an easy place to make a mistake. Sometimes, people look at the /56 and think of that as the first 14 hex digits, which is correct. However, they then copy the first 14 hex digits, and add a double colon, showing the following:

2000:1234:5678:**9A**::/56

This abbreviation is not correct, because it removed the trailing "00" at the end of the fourth quartet. So, be careful when abbreviating when the boundary is not at the edge of a quartet.

Once again, some extra practice can help. Table 25-6 uses examples that have a prefix length that is a multiple of 4, but is not on a quartet boundary, just to get some extra practice. The answers sit at the end of the chapter, in the section "Answers to Earlier Practice Problems."

Table 25-6. Finding the IPv6 Prefix from an Address/Length Value



Address/Length	Prefix
34BA:B:B:0:5555:0:6060:707/80	
3124::DEAD:CAFE:FF:FE00:1/80	
2BCD::FACE:BEFF:FEBE:CAFE/48	
3FED:F:E0:D00:FACE:BAFF:FE00:0/48	
210F:A:B:C:CCCC:B0B0:9999:9009/40	
34BA:B:B:0:5555:0:6060:707/36	
3124::DEAD:CAFE:FF:FE00:1/60	
2BCD::FACE:1:BEFF:FEBE:CAFE/56	
3FED:F:E0:D000:FACE:BAFF:FE00:0/52	
3BED:800:0:40:FACE:BAFF:FE00:0/44	

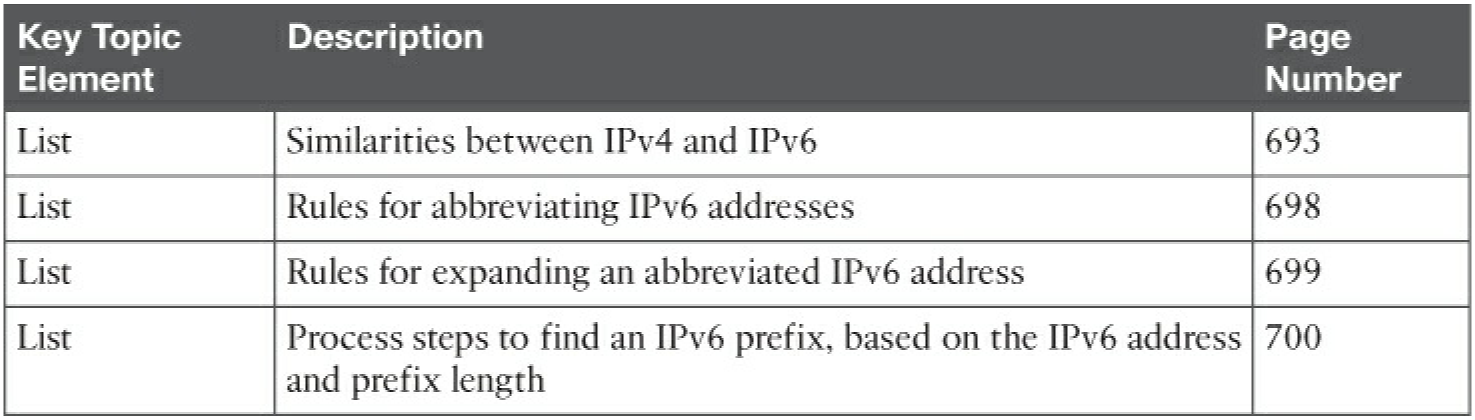
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 25-7 lists these key topics and where each is discussed.

Key Topic

Table 25-7. Key Topics for Chapter 25



Key Topic Element	Description	Page Number
List	Similarities between IPv4 and IPv6	693
List	Rules for abbreviating IPv6 addresses	698
List	Rules for expanding an abbreviated IPv6 address	699
List	Process steps to find an IPv6 prefix, based on the IPv6 address and prefix length	700

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, “Memory Tables Answer Key,” includes completed tables and lists for you to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

IPv4 address exhaustion
IETF
NAT
CIDR
IP version 6 (IPv6)
OSPF version 3 (OSPFv3)
EIGRP version 6 (EIGRPv6)
prefix
prefix length
quartet

Additional Practice with IPv6 Address Abbreviations

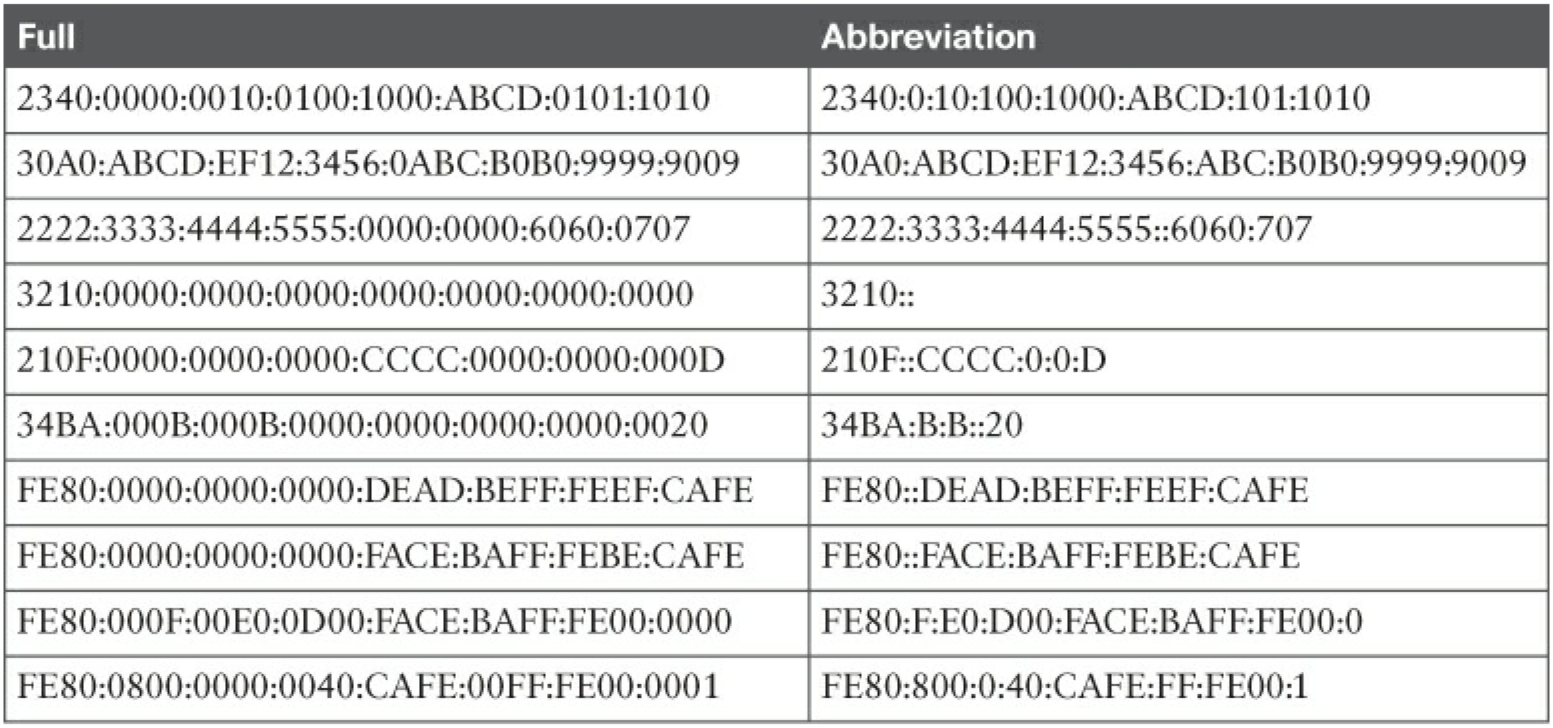
For additional practice abbreviating IPv6 addresses:

- DVD Appendix K, “Practice for Chapter 25: Fundamentals of IP Version 6,” has some additional practice problems listed.
- Create your own problems using any real router or simulator. Get into the router CLI, into configuration mode, and configure a 32-digit unabbreviated IPv6 address. Then predict the shortest abbreviation. Finally, use the **show ipv6 interface** command to see if the router used the same abbreviation you used.

Answers to Earlier Practice Problems

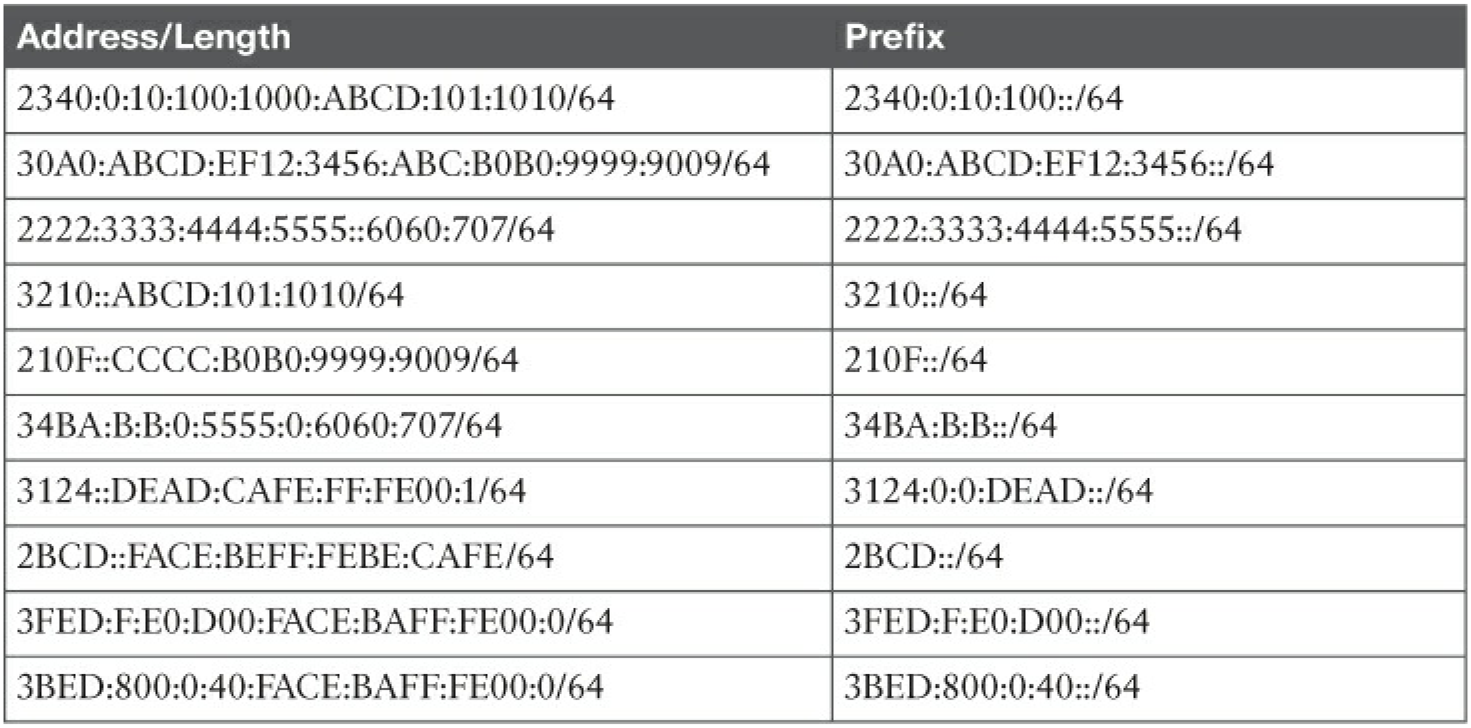
This chapter includes practice problems spread around different locations in the chapter. The answers are located in Tables 25-8, 25-9, and 25-10.

Table 25-8. Answers to Questions in the Earlier Table 25-4



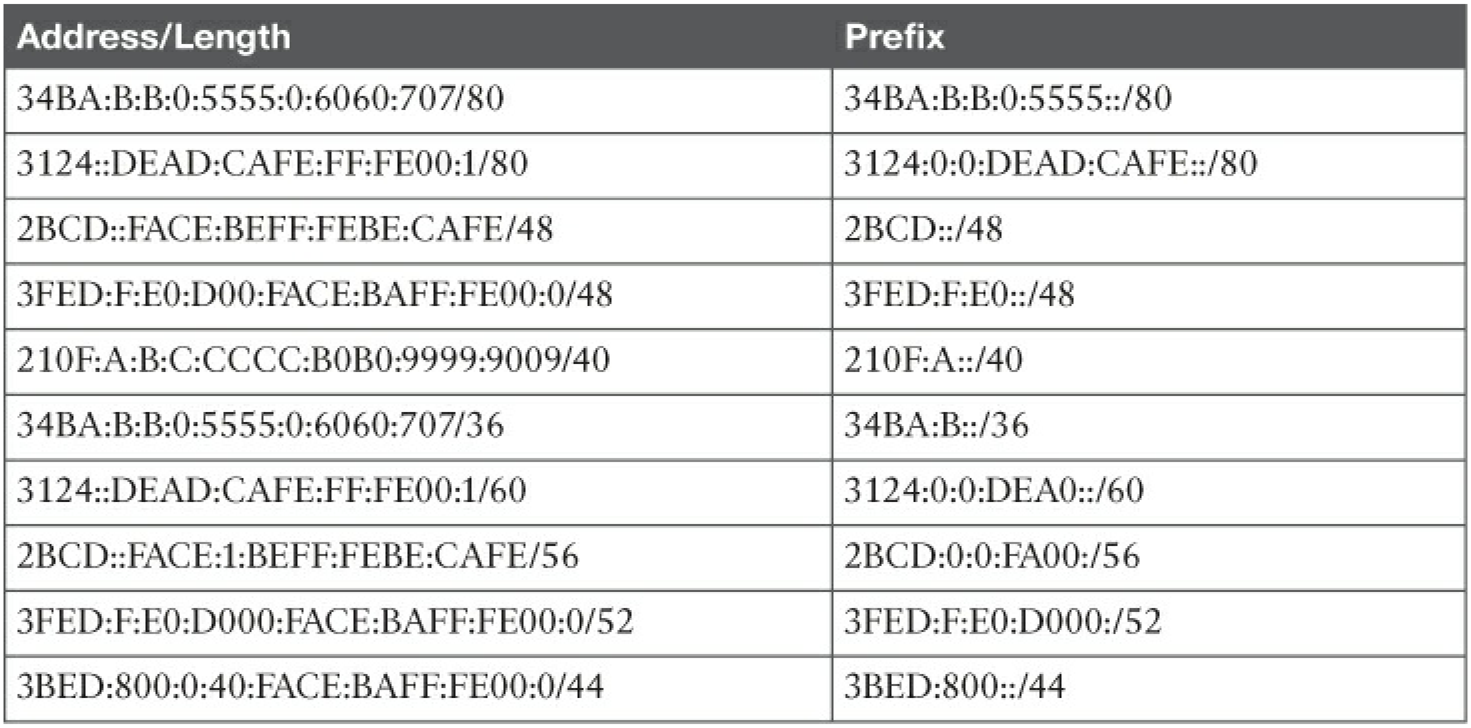
Full	Abbreviation
2340:0000:0010:0100:1000:ABCD:0101:1010	2340:0:10:100:1000:ABCD:101:1010
30A0:ABCD:EF12:3456:0ABC:B0B0:9999:9009	30A0:ABCD:EF12:3456:ABC:B0B0:9999:9009
2222:3333:4444:5555:0000:0000:6060:0707	2222:3333:4444:5555::6060:707
3210:0000:0000:0000:0000:0000:0000:0000	3210::
210F:0000:0000:0000:CCCC:0000:0000:000D	210F::CCCC:0:0:D
34BA:000B:000B:0000:0000:0000:0000:0020	34BA:B:B::20
FE80:0000:0000:0000:DEAD:BEFF:FEEF:CAFE	FE80::DEAD:BEFF:FEEF:CAFE
FE80:0000:0000:0000:FACE:BAFF:FEBE:CAFE	FE80::FACE:BAFF:FEBE:CAFE
FE80:000F:00E0:0D00:FACE:BAFF:FE00:0000	FE80:F:E0:D00:FACE:BAFF:FE00:0
FE80:0800:0000:0040:CAFE:00FF:FE00:0001	FE80:800:0:40:CAFE:FF:FE00:1

Table 25-9. Answers to Questions in the Earlier Table 25-5



Address/Length	Prefix
2340:0:10:100:1000:ABCD:101:1010/64	2340:0:10:100::/64
30A0:ABCD:EF12:3456:ABC:B0B0:9999:9009/64	30A0:ABCD:EF12:3456::/64
2222:3333:4444:5555::6060:707/64	2222:3333:4444:5555::/64
3210::ABCD:101:1010/64	3210::/64
210F::CCCC:B0B0:9999:9009/64	210F::/64
34BA:B:B:0:5555:0:6060:707/64	34BA:B:B::/64
3124::DEAD:CAFE:FF:FE00:1/64	3124:0:0:DEAD::/64
2BCD::FACE:BEFF:FEBE:CAFE/64	2BCD::/64
3FED:F:E0:D00:FACE:BAFF:FE00:0/64	3FED:F:E0:D00::/64
3BED:800:0:40:FACE:BAFF:FE00:0/64	3BED:800:0:40::/64

Table 25-10. Answers to Questions in the Earlier Table 25-6



Address/Length	Prefix
34BA:B:B:0:5555:0:6060:707/80	34BA:B:B:0:5555::/80
3124::DEAD:CAFE:FF:FE00:1/80	3124:0:0:DEAD:CAFE::/80
2BCD::FACE:BEFF:FEBE:CAFE/48	2BCD::/48
3FED:F:E0:D00:FACE:BAFF:FE00:0/48	3FED:F:E0::/48
210F:A:B:C:CCCC:B0B0:9999:9009/40	210F:A::/40
34BA:B:B:0:5555:0:6060:707/36	34BA:B::/36
3124::DEAD:CAFE:FF:FE00:1/60	3124:0:0:DEA0::/60
2BCD::FACE:1:BEFF:FEBE:CAFE/56	2BCD:0:0:FA00:/56
3FED:F:E0:D000:FACE:BAFF:FE00:0/52	3FED:F:E0:D000:/52
3BED:800:0:40:FACE:BAFF:FE00:0/44	3BED:800::/44

Chapter 26. IPv6 Addressing and Subnetting

This chapter covers the following exam topics:

- **IP addressing (IPv4 / IPv6)**
  - Identify the appropriate IPv6 addressing scheme to satisfy addressing requirements in a LAN/WAN environment.
  - Describe IPv6 addresses
    - Global unicast
    - Unique local
- **Troubleshooting**
  - Troubleshoot and correct common problems associated with IP addressing and host configurations.

IPv4 organizes the address space in a couple of ways. First, IPv4 splits addresses by class, with Classes A, B, and C defining unicast IPv4 addresses. (The term *unicast* refers to the fact that each address is used by only one interface.) Then, within the Class A, B, and C address range, the Internet Assigned Numbers Authority (IANA) and the Internet Corporation for Assigned Names and Numbers (ICANN) reserve most of the addresses as public IPv4 addresses, with a few reserved as private IPv4 addresses.

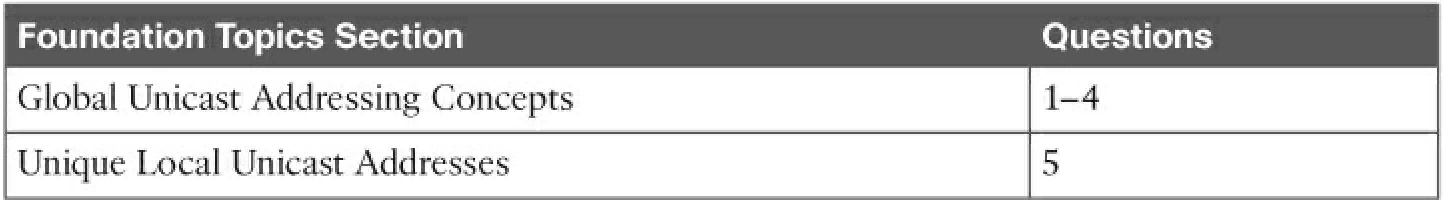
IPv6 does not use any concept like the classful network concept used by IPv4. However, IANA does still reserve some IPv6 address ranges for specific purposes, even with some address ranges that serve as both public IPv6 addresses and private IPv6 addresses. IANA also attempts to take a practical approach to reserving ranges of the entire IPv6 address space for different purposes, using the wisdom gained from several decades of fast growth in the IPv4 Internet.

This chapter has two major sections. The first examines *global unicast addresses*, which serve as public IPv6 addresses. The second major section looks at *unique local addresses*, which serve as private IPv6 addresses.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 26-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Global Unicast Addressing Concepts	1–4
Unique Local Unicast Addresses	5

1. Which of the following IPv6 addresses appears to be a unique local unicast address, based on its first few hex digits?
   - **a.** 3123:1:3:5::1
   - **b.** FE80::1234:56FF:FE78:9ABC
   - **c.** FDAD::1
   - **d.** FF00::5
2. Which of the following IPv6 addresses appears to be a global unicast address, based on its first few hex digits?
   - **a.** 3123:1:3:5::1
   - **b.** FE80::1234:56FF:FE78:9ABC
   - **c.** FDAD::1
   - **d.** FF00::5
3. When subnetting an IPv6 address block, an engineer shows a drawing that breaks the address structure into three pieces. Comparing this concept to a three-part IPv4 address structure, which part of the IPv6 address structure is most like the IPv4 network part of the address?
   - **a.** Subnet
   - **b.** Interface ID
   - **c.** Network
   - **d.** Global routing prefix
   - **e.** Subnet router anycast
4. When subnetting an IPv6 address block, an engineer shows a drawing that breaks the address structure into three pieces. Assuming that all subnets use the same prefix length, which of the following answers lists the name of the field on the far right side of the address?
   - **a.** Subnet

- **b.** Interface ID
- **c.** Network
- **d.** Global routing prefix
- **e.** Subnet router anycast

5. For the IPv6 address FD00:1234:5678:9ABC:DEF1:2345:6789:ABCD, which part of the address is considered the global ID of the unique local address?

- **a.** None; this address has no global ID.
- **b.** 00:1234:5678:9ABC
- **c.** DEF1:2345:6789:ABCD
- **d.** 00:1234:5678
- **e.** FD00

Answers to the "Do I Know This Already?" quiz:

1 C **2** A **3** D **4** B **5** D

Foundation Topics

Global Unicast Addressing Concepts

This first major section of the chapter focuses on one type of unicast IPv6 addresses: global unicast addresses. As it turns out, many of the general concepts and processes behind these global unicast IPv6 addresses follow the original intent for public IPv4 addresses. So, this section begins with a review of some IPv4 concepts, followed by the details of how a company can use global unicast addresses.

This first section also discusses IPv6 subnetting, and the entire process of taking a block of global unicast addresses and creating subnets for one company. This process takes a globally unique global routing prefix, creates IPv6 subnets, and assigns IPv6 addresses from within each subnet, much like with IPv4.

A Brief Review of Public and Private IPv4 Addresses

In the history of IPv4 addressing, the world started out with a plan that gave every single host a globally unique public IPv4 address. However, as discussed in several places already, the IPv4 address space had too few addresses. So, in the 1990s, companies started using addresses from the private IPv4 address range, as defined in RFC 1918. These companies either simply did not connect to the Internet, or to connect to the Internet, they used NAT, sharing a few public globally unique IPv4 addresses for all host connections into the Internet.

The next few pages briefly review some of the major concepts behind using public and private addresses in IPv4, as a comparison to the equivalent addresses in IPv6.

Review of Public IPv4 Addressing Concepts

In the original design for the IPv4 Internet, the Internet relied on every IPv4 host using a unicast address that was unique in the universe. To make that happen, three major steps in planning had to occur so that each unicast address was unique:

- The company or organization asked for and received the rights to the exclusive use of a public Class A, B, or C IPv4 network number.
- The engineers at that company subdivided that classful network into smaller subnets, making sure to use each subnet in only one place in the company.
- The engineers chose individual IPv4 addresses from within each subnet, making sure to use each address for only one host interface.

Figure 26-1 shows a conceptual view of the breakdown of a classful IPv4 network into subnets, with each subnet holding individual unicast IPv4 addresses. The figure represents the entire public Class A, B, or C network with the largest rectangle, and each individual unicast IPv4 address using a mailbox icon.

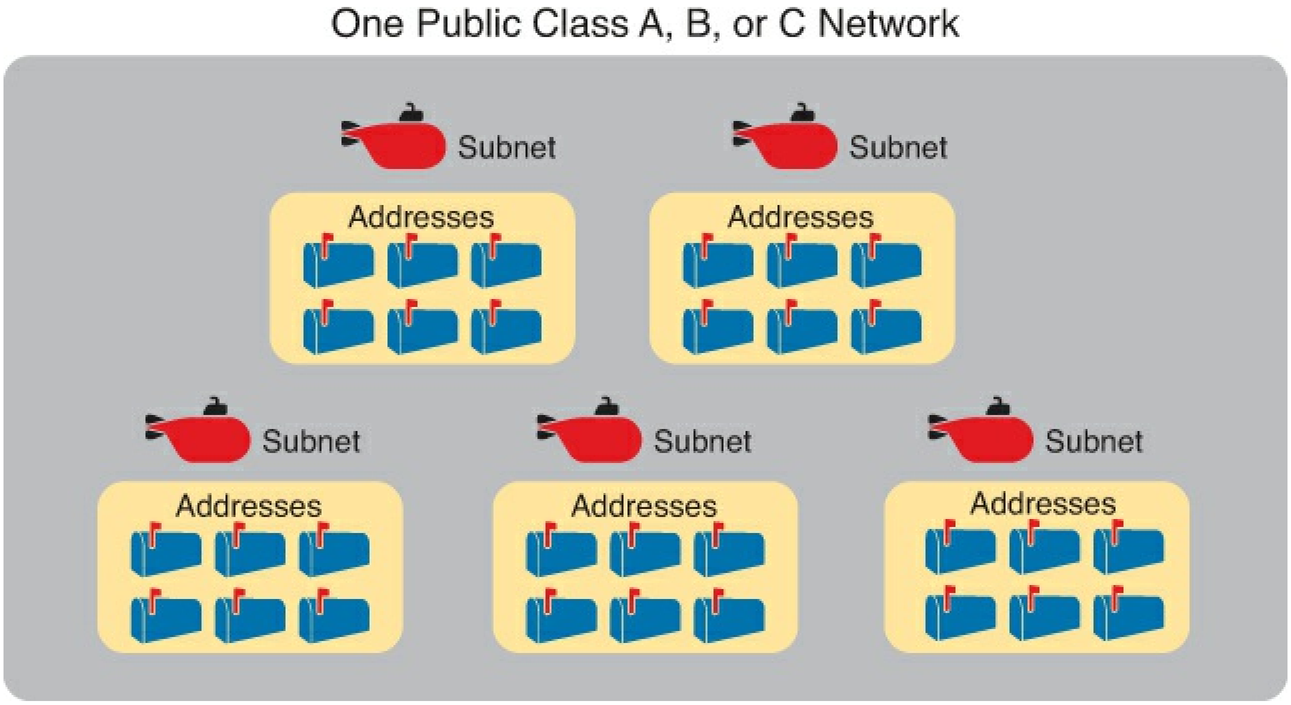

One Public Class A, B, or C Network
Subnet
Addresses
Subnet
Addresses
Subnet
Addresses
Subnet
Addresses
Subnet
Addresses

Figure 26-1. Unique IP Network, Unique Subnets, and Unique Addresses Per Subnet

While Figure 26-1 shows some of the general concepts behind how an enterprise could take a classful IPv4 network and subdivide it into subnets, the network engineer must also plan where to use subnets in the enterprise internetwork. By now, the ideas should be relatively familiar, but for review, for the technologies discussed for the CCENT and CCNA certifications, the following each need a separate IPv4 subnet:

Key Topic

- VLAN
- Point-to-point serial link
- Ethernet emulation WAN link (EoMPLS)
- Frame Relay PVC (not discussed in detail until the ICND2 book)

For example, in the enterprise internetwork shown in Figure 26-2, the enterprise network engineer plans for five subnets. In this example, each router LAN interface connects to a LAN that uses a single VLAN, for a total of three subnets for the three VLANs. The serial and Ethernet WAN links each need a subnet as well. (Subnets for the Internet will be assigned by the various ISPs.)

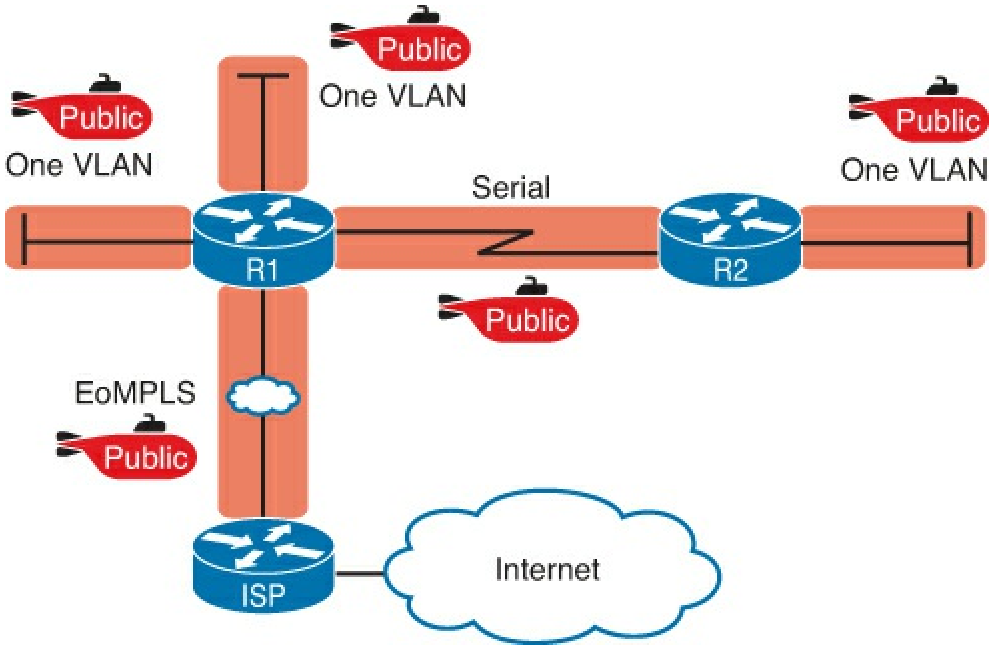

Public
One VLAN
Public
One VLAN
Public
One VLAN
Serial
R1
R2
Public
EoMPLS
Public
ISP
Internet

Figure 26-2. Example Internetwork with Five IPv4 Subnets with Public Addresses

Review of Private IPv4 Addressing Concepts

Frankly, today, most companies do not use public IPv4 addresses throughout their enterprise internetworks. The world starting running out of IPv4 addresses, and this IPv4 address exhaustion problem required some changes.

Today, most enterprise internetworks use private IPv4 addresses for most hosts. The reason being that using private IPv4 addresses (per RFC 1918), along with NAT/PAT, significantly reduces the number of public IPv4 addresses needed by that organization. Using private IPv4 addresses, with NAT/PAT, allowed one public IPv4 address to support a fairly large enterprise internetwork, putting off the day when the world would run out of public IPv4 addresses. (See Chapter 25's section "The Historical Reasons for IPv6" for a review of some of the events that drove the need for private IPv4 addresses and NAT/PAT.)

For comparison, Figure 26-3 repeats the same enterprise internetwork design shown in Figure 26-3. However, in this case, the enterprise uses private IPv4 addresses in most of the network, with Router R1 performing NAT/PAT, reducing the number of required public IPv4 addresses.

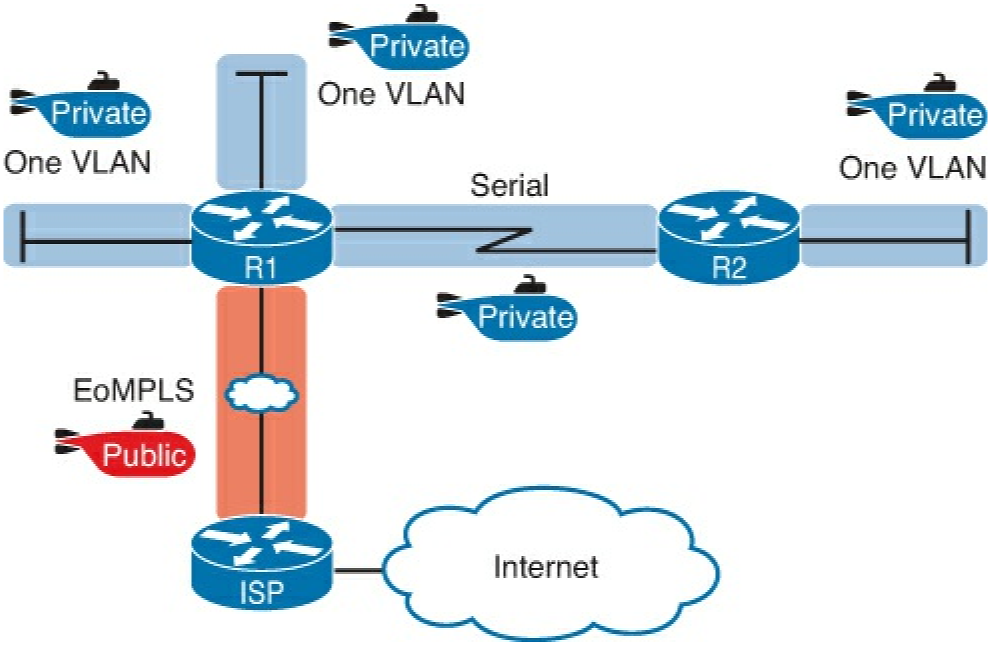


Figure 26-3. Example Internetwork with Five IPv4 Subnets

Public and Private IPv6 Addresses

IPv6 allows two similar options for unicast addressing, beginning with *global unicast* addressing. These addresses work like the original design for IPv4 using public addresses. Similar to public IPv4 addresses, IPv6 global unicast addresses rely on an administrative process that assigns each company a unique IPv6 address block. Each company then subnets this IPv6 address block, and only uses addresses from within that block. The result: That company uses addresses that are unique across the globe as well.

The second IPv6 option uses *unique local* IPv6 addresses, which work more like the IPv4 private addresses. Companies that do not plan to connect to the Internet, and companies that plan to use IPv6 NAT, can use these private unique local addresses. The process also works similarly to IPv4: The engineer can read the details in an RFC, pick some numbers, and start assigning IPv6 addresses, without having to register with IANA or any other authority.

The following lists summarizes these points for quicker review:

Key Topic

Global Unicast: Addresses that work like public IPv4 addresses. The organization that needs IPv6 addresses asks for a registered IPv6 address block, which is assigned as a global routing prefix. After that, only that organization uses the addresses inside that block of addresses, that is, the addresses that begin with the assigned prefix.

Unique Local: Works somewhat like private IPv4 addresses, with the possibility that multiple organizations use the exact same addresses, and with no requirement for registering with any numbering authority

The rest of this first major section of the chapter examines global unicast addresses in more detail, while the second major section of the chapter examines unique local addresses.

Note

Just for completeness sake, note that you might also find documentation about another range of addresses called *site local*. These addresses, defined by prefix FEC0::/10 (so that they begin with FEC, FED, FEE, or FEF) were originally intended to be used like IPv4 private addresses. They have now been removed from the IPv6 standards.

The IPv6 Global Routing Prefix

IPv6 global unicast addresses allow IPv6 to work more like the original design of the IPv4 Internet. In other words, each organization asks for a block of IPv6 addresses, which no one else can use. That organization further subdivides the address block into smaller chunks, called subnets. Finally, to choose what IPv6 address to use for any host, the engineer chooses an address from the right subnet.

That reserved block of IPv6 addresses—a set of addresses that only one company can use—is called a *global routing prefix*. Each organization that wants to connect to the Internet, and use IPv6 global unicast addresses, should ask for and receive a global routing prefix. Very generally, you can think of the global routing prefix like an IPv4 Class A, B, or C network number from the range of public IPv4 addresses.

The term *global routing prefix* might not make you think of a block of IPv6 addresses at first. The term actually refers to the idea that Internet routers can have one route that refers to all the addresses inside the address block, without a need to have routes for smaller parts of that block. For example, Figure 26-4 shows three companies, with three different IPv6 global routing prefixes; the router on the right (R4) has one IPv6 route for each global routing prefix.

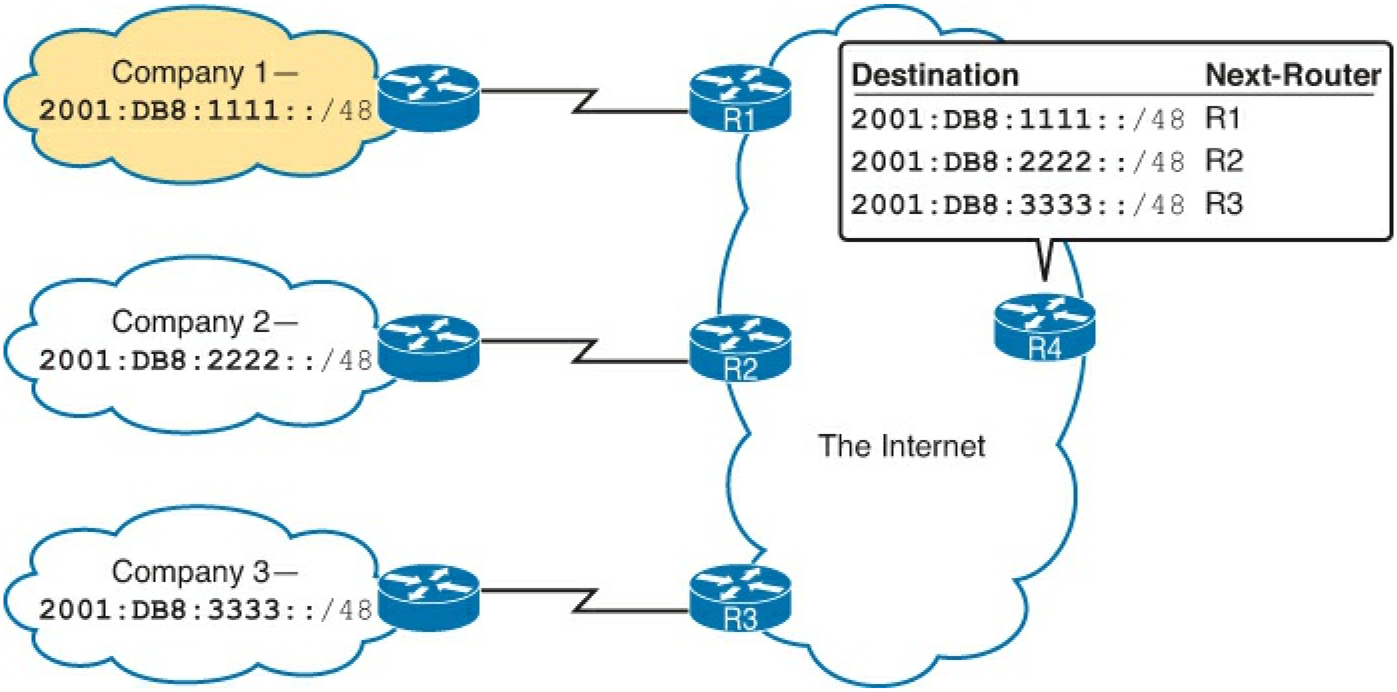

Company 1—
2001:DB8:1111::/48
Company 2—
2001:DB8:2222::/48
Company 3—
2001:DB8:3333::/48
R1
R2
R3
R4
The Internet
Destination
Next-Router
2001:DB8:1111::/48 R1
2001:DB8:2222::/48 R2
2001:DB8:3333::/48 R3

Figure 26-4. Three Global Routing Prefixes, with One Route per Prefix

The global routing prefix sets those IPv6 addresses apart for use by that one company, just like a public IPv4 network or CIDR address block does in IPv4. All IPv6 addresses inside that company should begin with that global routing prefix, to avoid using other companies' IPv6 addresses. No other companies should use IPv6 addresses with that same prefix. And thankfully, IPv6 has plenty of space to allow all companies to have a global routing prefix, with plenty of addresses.

Both the IPv6 and IPv4 address assignment process rely on the same organizations: IANA (along with ICANN), the Regional Internet Registries (RIR), and ISPs. For example, an imaginary company, Company1, received the assignment of a global routing prefix. The prefix means "All addresses whose first 12 hex digits are 2001:0DB8:1111," as represented by prefix 2001:0DB8:1111::/48. To receive that assignment, the process shown in Figure 26-5 happened.

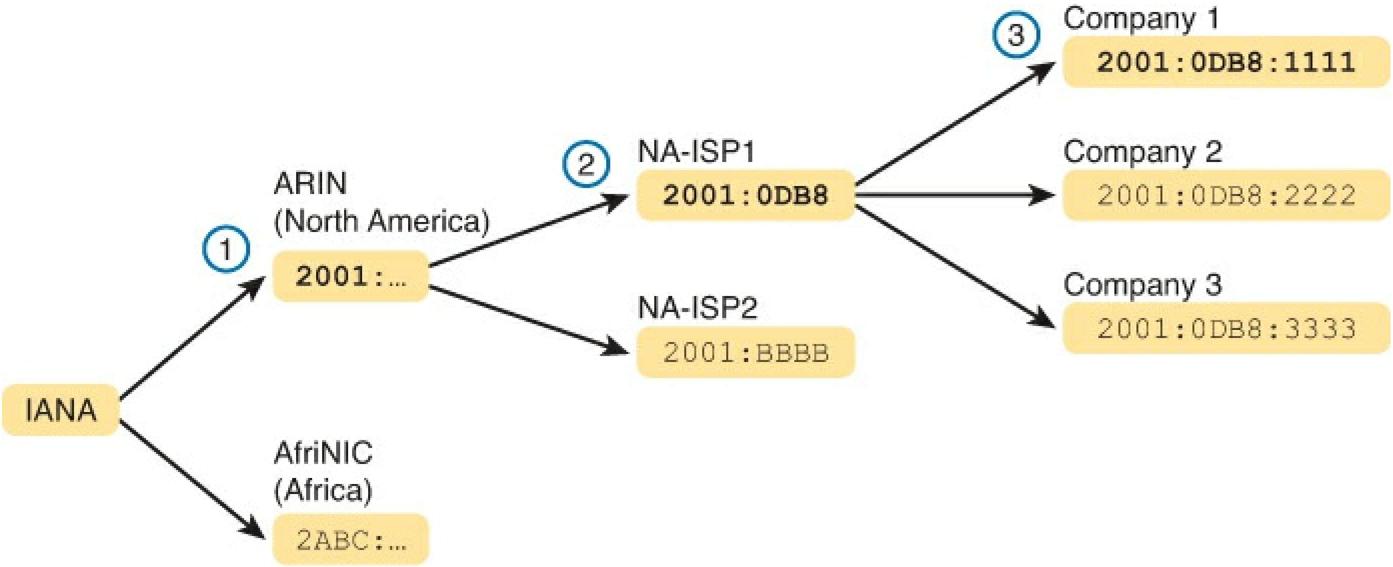

③
Company 1
2001:0DB8:1111
②
NA-ISP1
2001:0DB8
Company 2
2001:0DB8:2222
ARIN
(North America)
①
2001:...
Company 3
2001:0DB8:3333
NA-ISP2
2001:BBBB
IANA
AfriNIC
(Africa)
2ABC:...

Figure 26-5. Prefix Assignment with IANA, RIRs, and ISPs

The event timeline in the figure uses a left-to-right flow; in other words, the event on the far left must happen first. Following the flow from left to right in the figure:

1. **IANA gives ARIN prefix 2001::/16**: ARIN (the RIR for North America) asks IANA for the assignment of a large block of addresses. In this imaginary example, IANA gives ARIN a prefix of "all addresses that begin 2001," or 2001::/16.
2. **ARIN gives NA-ISP1 prefix 2001:0DB8::/32:** NA-ISP1, an imaginary ISP based in North America, asks ARIN for a new IPv6 prefix. ARIN takes a subset of its 2001::/16 prefix, specifically all addresses that begin with the 32 bits (8 hex digits) 2001:0DB8, and gives it to the ISP.
3. **NA-ISP1 gives Company 1 2002:0DB8:1111::/48:** Company 1 decides to start supporting IPv6, so it goes to its ISP, NA-ISP1, to ask for a block of global unicast addresses. NA-ISP1 gives Company 1 a "small" piece of NA-ISP1's address block, in this case the addresses that begin with the 48 bits (12 hex digits) of 2001:0DB8:1111 (2001:0DB8:1111::/48).

> **Note**
>
> If you do not plan to connect to the Internet using IPv6 for a while, and just want to experiment, you do not need to ask for an IPv6 global routing prefix to be assigned. Just make up IPv6 addresses and configure your devices.

Address Ranges for Global Unicast Addresses

Global unicast addresses make up the majority of the IPv6 address space. However, unlike IPv4, the rules for which IPv6 address fall into which category are purposefully more flexible than they were with IPv4 and the rules for IPv4 Classes A, B, C, D, and E.

Originally, IANA reserved all IPv6 addresses that begin with hex 2 or 3 as global unicast addresses. (This address range can be written succinctly as prefix 2000::/3.)

Later RFCs made the global unicast address range wider, basically include all IPv6 addresses not otherwise allocated for other purposes. For example, the unique local unicast addresses, discussed later in this chapter, all start with hex FD. So, while global unicast addresses would not include any addresses that begin with FD, any address ranges that are not specifically reserved, for now, are considered to be global unicast addresses.

Finally, just because an amazingly enormous number of addresses sit within the global unicast address range, IANA does not assign prefixes from all over the address range. IPv4 has survived well for over 30 years with an admittedly too-small address size. By making smart and practical choices in assigning IPv6 addresses, the IPv6 address space could last much longer than IPv4.

Table 26-2 lists the address prefixes discussed in this book, and their purpose.

Key Topic

Table 26-2. Some Types of IPv6 Addresses and Their First Hex Digit(s)

Address Type	First Hex Digits
Global Unicast	2 or 3 (originally); all not otherwise reserved (today)
Unique Local	FD
Multicast	FF
Link-Local	FE80

IPv6 Subnetting Using Global Unicast Addresses

After an enterprise has a block of reserved global unicast addresses—in other words, a global routing prefix—the company needs to subdivide that large address block into subnets.

Subnetting IPv6 addresses works generally like IPv4, but with mostly simpler math (hoorah!). Because of the absolutely large number of addresses available, most everyone uses the easiest possible IPv6 prefix length: *64. Using* 64 as the prefix length for all subnets makes the IPv6 subnetting math just as easy as using a *24 mask for all IPv4 subnets. Additionally, the dynamic IPv6 address assignment process works better with a* 64 prefix length as well, so in practice, and in this book, expect IPv6 designs to use a /64 prefix length.

This section does walk you through the different parts of IPv6 subnetting, while mostly using examples that use a /64 prefix length. The discussion defines the rules about which addresses should be in the same subnet, and which addresses need to be in different subnets. Plus this section looks at how to analyze the global routing prefix and associated prefix length to find all the IPv6 prefixes (subnet IDs) and the addresses in each subnet.

Note

If the IPv4 subnetting concepts are a little vague, you might want to reread Chapter 11, "Perspectives on IPv4 Subnetting," which discusses the subnetting concepts for IPv4.

Deciding Where IPv6 Subnets Are Needed

First, IPv6 and IPv4 both use the same concepts about where a subnet is needed: one for each VLAN and one for each point-to-point WAN connection (serial and EoMPLS), with the subnetting details for Frame Relay being discussed in the ICND2 book. Figure 26-6 shows an example of the idea, using the small enterprise internetwork of Company 1. Company 1 has two LANs, with a point-to-point serial link connecting the sites. It also has an Ethernet WAN link connected to an ISP. Using the same logic you would use for IPv4, Company 1 needs four IPv6 subnets.

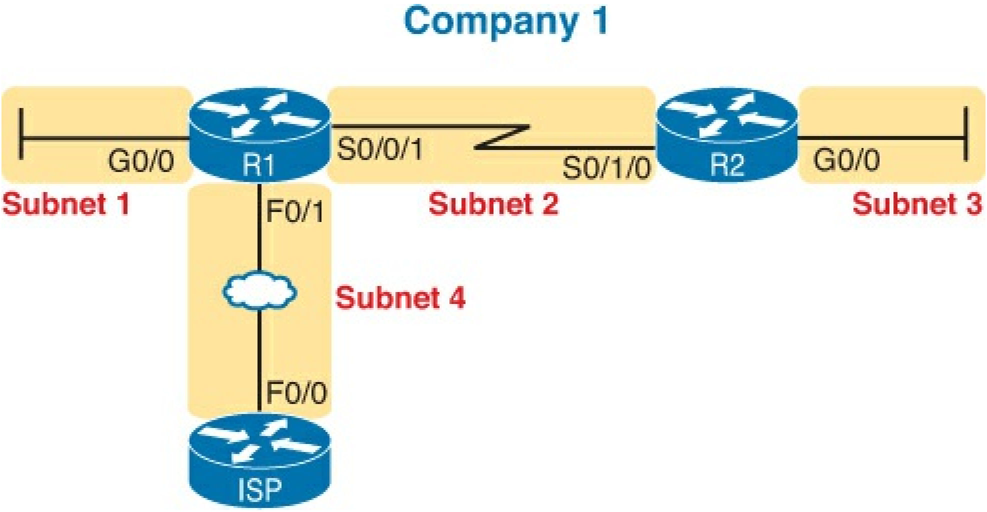


Figure 26-6. Locations for IPv6 Subnets

The Mechanics of Subnetting IPv6 Global Unicast Addresses

To understand how to subnet your one large block of IPv6 addresses, you need to understand some of the theory and mechanisms IPv6 uses. To learn those details, it can help to compare IPv6 with some similar concepts from IPv4.

With IPv4, without subnetting, an address has two parts: a network part and a host part. Class A, B, and C rules define the length of the network part, with the host part making up the rest of the 32-bit IPv4 address, as shown in Figure 26-7.

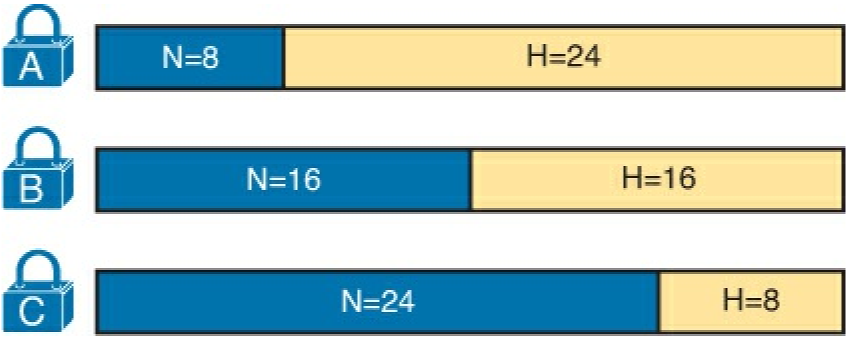


Figure 26-7. Classful View of Unsubnetted IPv4 Networks

To subnet an IPv4 Class A, B, or C network, the network engineer for the enterprise makes some choices. Conceptually, the engineer creates a three-part view of the addresses, adding a subnet field in the center, while shortening the host field. (Many people call this "borrowing host bits.") The size of the network part stays locked per the Class A, B, and C rules, with the line between the subnet and host part being flexible, based on the choice of subnet mask. Figure 26-8 shows the idea, for a subnetted Class B network.

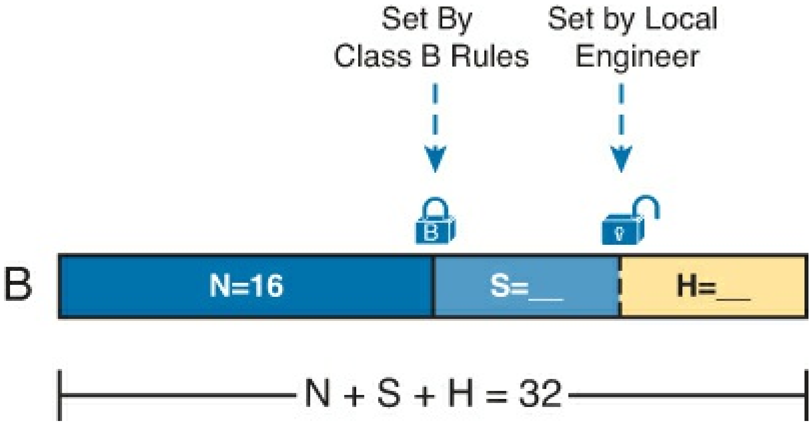


Figure 26-8. Classful View of Subnetted IPv4 Networks

IPv6 uses a similar concept, with the details in Figure 26-9. The structure shows three major parts, beginning with the global routing prefix, which is the initial value that must be the same in all IPv6 addresses inside the enterprise. The address ends with the interface ID, which acts like the IPv4 host field. The subnet field sits between the two other fields, used as a way to number and identify subnets, much like the subnet field in IPv4 addresses.

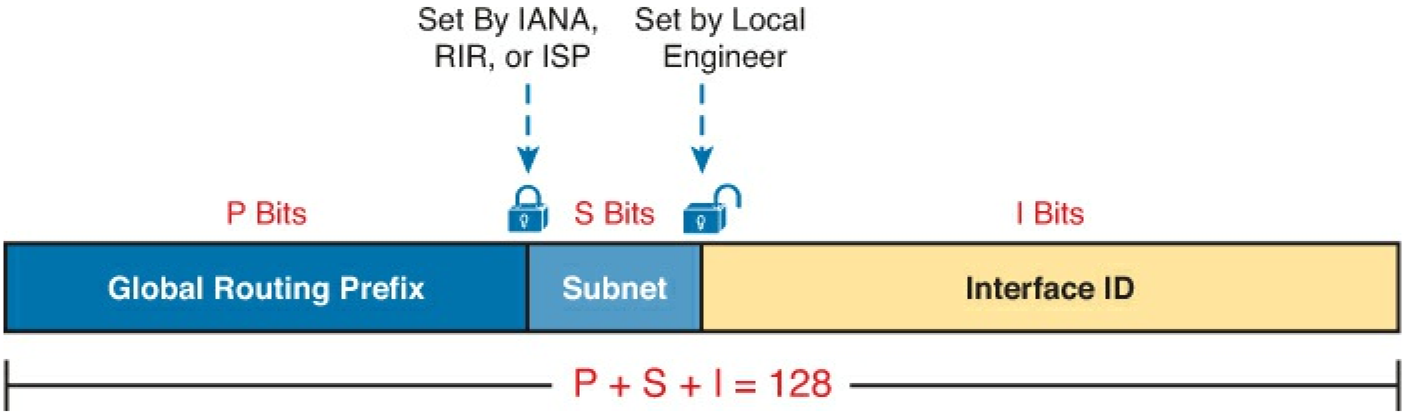


Figure 26-9. Structure of Subnetted IPv6 Global Unicast Addresses

First, just think about the general idea with IPv6, comparing Figure 26-9 to Figure 26-8. The IPv6 global routing prefix acts like the IPv4 network part of the address structure. The IPv6 subnet part acts like the IPv4 subnet part. And the right side of the IPv6, formally called the interface ID (short for interface identifier), acts like the IPv4 host field.

Now focus on the IPv6 global routing prefix and its prefix length. Unlike IPv4, IPv6 has no concept of address classes, so no preset rules determine the prefix length of the global routing prefix. However, when a company applies to an ISP, RIR, or any other organization that can allocate a global routing prefix, that allocation includes both the prefix, and the prefix length. After a company receives a global routing prefix and that prefix length, the length of the prefix typically does not change over time, and is basically locked. (Note that the prefix length of the global routing prefix is often between *32 and* 48, or possibly as long as /56.)

Next, look to the right side of Figure 26-9 to the interface ID field. For several reasons that become more obvious the more you learn about IPv6, this field is often 64 bits long. Does it have to be 64 bits long? No. However, using a 64-bit interface ID field works well in real networks, and there are no reasons to avoid using a 64 bit interface ID field.

Finally, look to the center of Figure 26-9, and the subnet field. Similar to IPv4, this field creates a place with which to number IPv6 subnets. The length of the subnet field is based on the other two facts: the length of the global routing prefix and the length of the interface ID. And with the commonly used 64-bit interface ID field, the subnet field is typically 64 – P bits, with P being the length of the global routing prefix.

Next, consider the structure of a specific global unicast IPv6 address, 2001:0DB8:1111:0001:0000:0000:0000:0001, as seen in Figure 26-10. In this case:

- The company was assigned prefix 2001:0DB8:1111, with prefix length /48.
- The company uses the usual 64-bit interface ID.
- The company has a subnet field of 16 bits, allowing for 2^{16} IPv6 subnets.

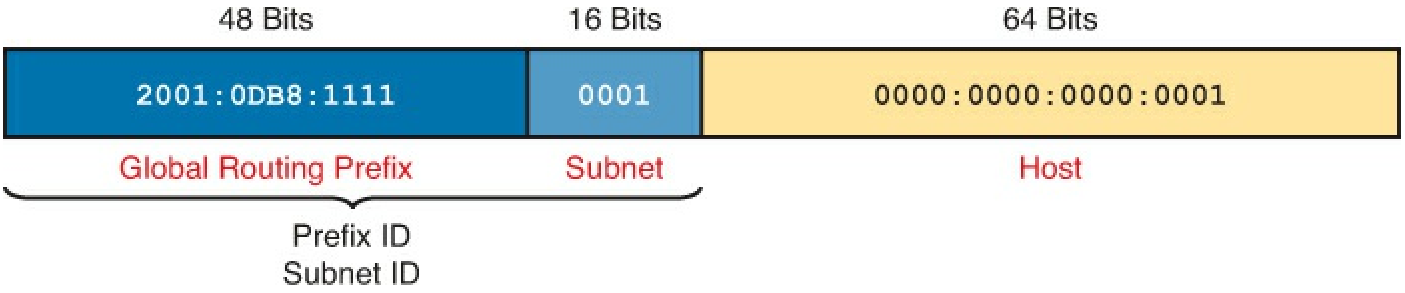


Figure 26-10. Address Structure for Company 1 Example

The example in Figure 26-10, along with a little math, shows one reason why so many companies use a /64 prefix length for all subnets. With this structure, Company 1 can support 2^{16} possible subnets (65,536). Few companies need that many subnets. Then, each subnet supports over 10^{18} addresses per subnet (2^{64}, minus some reserved values). So, for both subnets and hosts, the address structure supports far more than are needed. Plus, the /64 prefix length for all subnets makes the math simple, because it cuts the 128-bit IPv6 address in half.

Listing the IPv6 Subnet Identifier

Like with IPv4, IPv6 needs to identify each IPv6 subnet with some kind of a subnet identifier, or subnet ID. Figure 26-10 lists the informal names for this number (subnet ID), and the more formal name (prefix ID). Routers then list the IPv6 subnet ID in routing tables, along with the prefix length.

Chapter 25, "Fundamentals of IP Version 6," has already discussed how to find the subnet ID, given an IPv6 address and prefix length. The math works the same way when working with global unicasts, as well as the unique local addresses discussed later in the chapter. Because Chapter 25 has already discussed the math, this chapter does not repeat the math. However, for completeness, the example in Figure 26-10, the subnet ID would be

2001:DB8:1111:1::/64

List All IPv6 Subnets

With IPv4, if you choose to use a single subnet mask for all subnets, you can sit and write down all the subnets of a Class A, B, or C network using that one subnet mask. With IPv6, the same ideas apply. If you plan to use a single prefix length for all subnets, you can start with the global routing prefix and write down all the IPv6 subnet IDs as well.

To find all the subnet IDs, you simply need to find all the unique values that will fit inside the subnet part of the IPv6 address, basically following these rules:

Key Topic

- All subnet IDs begin with the global routing prefix.
- Use a different value in the subnet field to identify each different subnet.
- All subnet IDs have all 0s in the interface ID.

As an example, take the IPv6 design shown in Figure 26-10, and think about all the subnet IDs. First, all subnets will use the commonly used *64 prefix length. This company uses a global routing prefix of 2001:0DB8:1111::*48, which defines the first 12 hex digits of all the subnet IDs. To find all the possible IPv6 subnet IDs, think of all the combinations of unique values in the fourth quartet, and then represent the last four quartets of all 0s with a :: symbol. Figure 26-11 shows the beginning of just such a list.

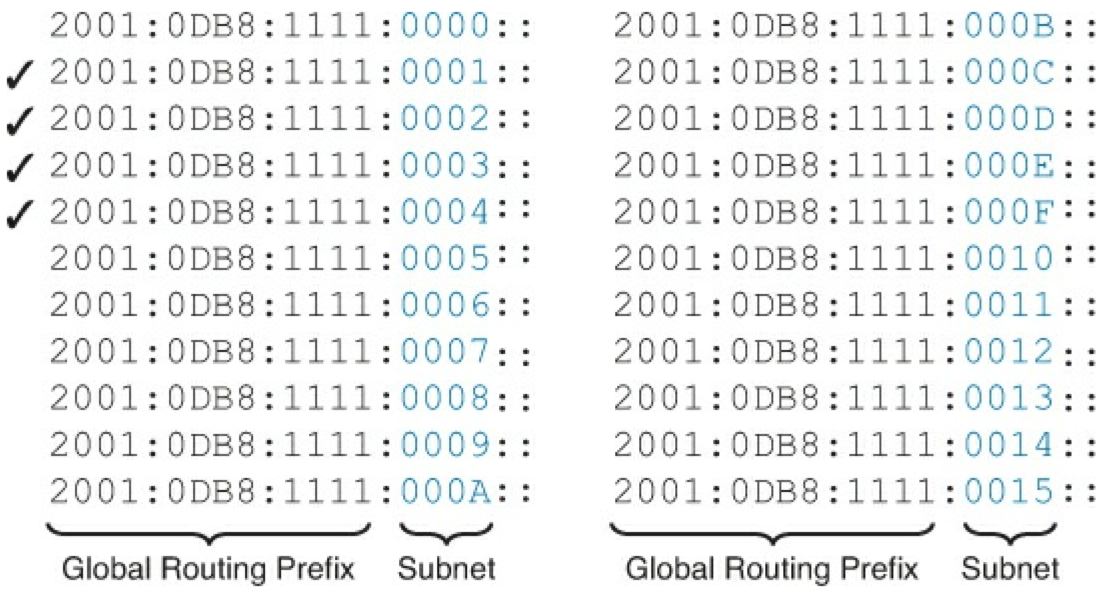

2001:0DB8:1111:0000::
✓ 2001:0DB8:1111:0001::
✓ 2001:0DB8:1111:0002::
✓ 2001:0DB8:1111:0003::
✓ 2001:0DB8:1111:0004::
2001:0DB8:1111:0005::
2001:0DB8:1111:0006::
2001:0DB8:1111:0007::
2001:0DB8:1111:0008::
2001:0DB8:1111:0009::
2001:0DB8:1111:000A::
2001:0DB8:1111:000B::
2001:0DB8:1111:000C::
2001:0DB8:1111:000D::
2001:0DB8:1111:000E::
2001:0DB8:1111:000F::
2001:0DB8:1111:0010::
2001:0DB8:1111:0011::
2001:0DB8:1111:0012::
2001:0DB8:1111:0013::
2001:0DB8:1111:0014::
2001:0DB8:1111:0015::

Figure 26-11. First 22 Possible Subnets with a 16-bit Subnet Field in This Example

The example allows for 65,536 subnets, so clearly the example will not list all the possible subnets. However, in that fourth quartet, all combinations of hex values would be allowed.

> **Note**
>
> The IPv6 subnet ID, more formally called the *subnet router anycast address*, is reserved, and should not be used as an IPv6 address for any host.

Assign Subnets to the Internetwork Topology

After an engineer lists all the possible subnet IDs (based on the subnet design), the next step is to choose which subnet ID to use for each link that needs an IPv6 subnet. Just like with IPv4, each VLAN, each serial link, each EoMPLS link, and many other data link instances need an IPv6 subnet.

Figure 26-12 shows an example using Company 1 again. The figure uses the four subnets from Figure 26-11 that have check marks beside them. The check marks are just a reminder to not use those four subnets in other locations.

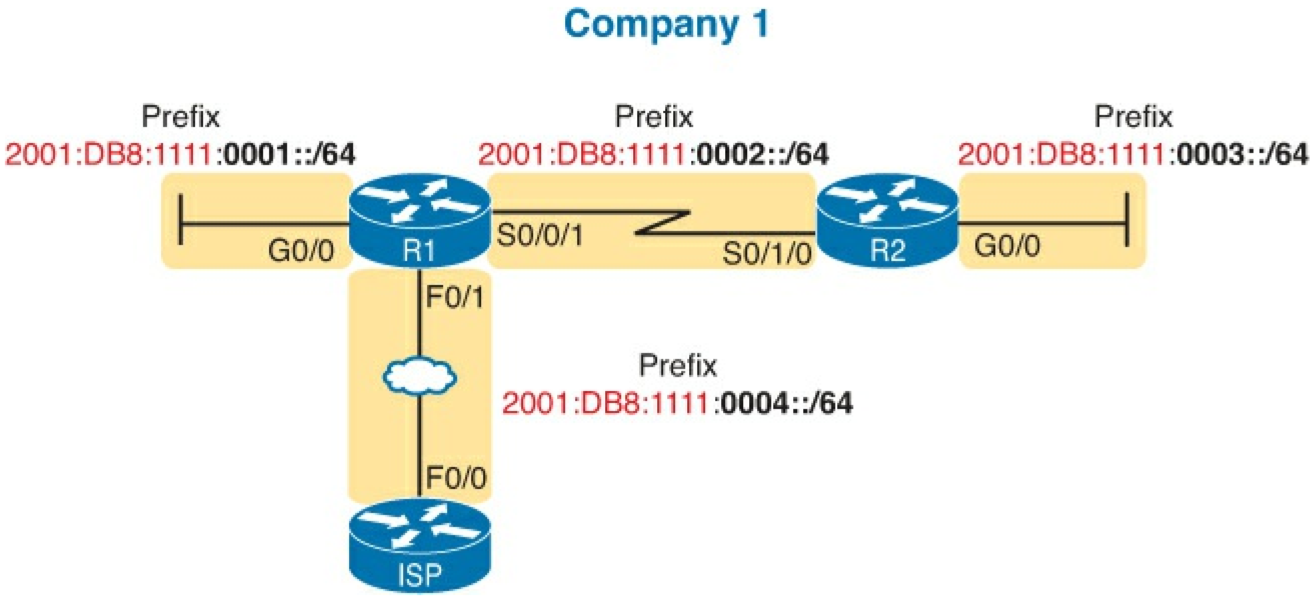


Figure 26-12. Subnets in Company 1, with Global Routing Prefix of 2001:0DB8:1111::/48

Assigning Addresses to Hosts in a Subnet

Now that the engineer has planned which IPv6 subnet will be used in each location, the individual IPv6 addressing can be planned and implemented. Each address must be unique, in that no other host interface uses the same IPv6 address. Also, the hosts cannot use the subnet ID itself.

The process of assigning IPv6 addresses to interfaces works similarly to IPv4. Addresses can be configured statically, along with the prefix length, default router, and DNS IPv6 addresses. Alternately, hosts can learn these same settings dynamically, using either DHCP or other a built-in IPv6 mechanism called Stateless Address Autoconfiguration, or SLAAC.

For example, Figure 26-13 shows some static IP addresses that could be chosen for the router interfaces based on the subnet choices shown in Figure 26-12. In each case, the router interfaces use an interface ID that is a relatively low number, easily remembered.

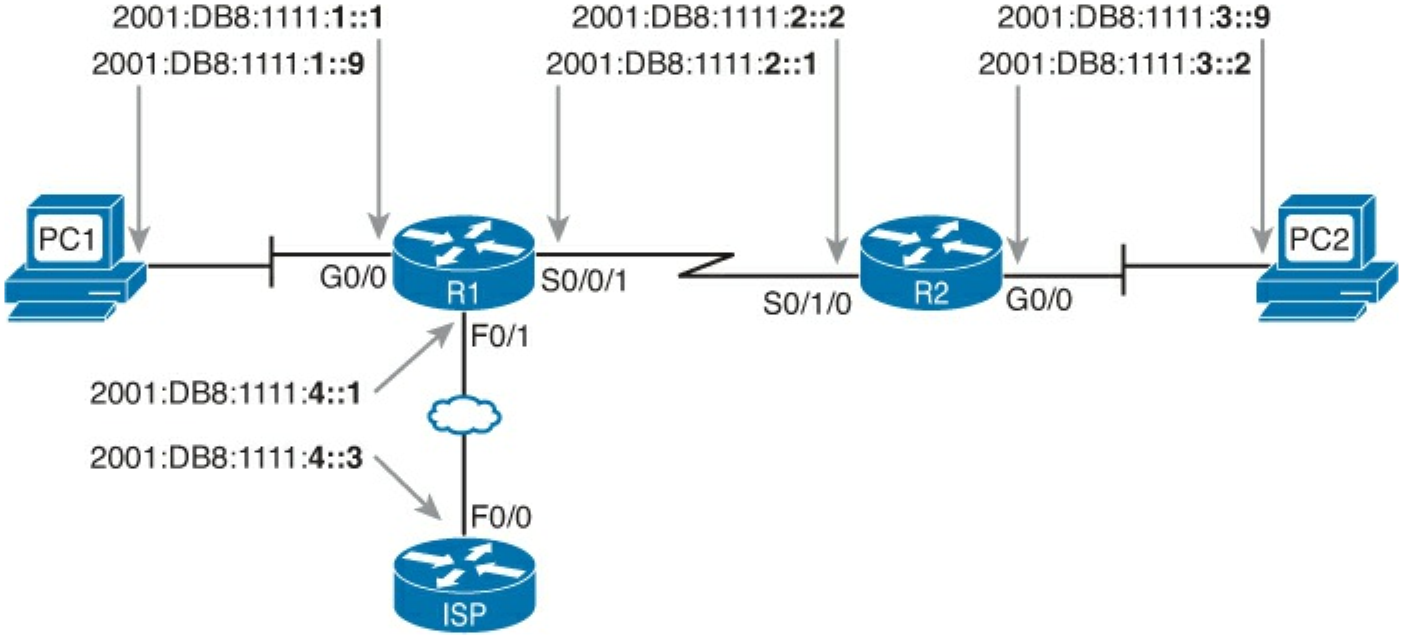

2001:DB8:1111:1::1
2001:DB8:1111:1::9
2001:DB8:1111:2::2
2001:DB8:1111:2::1
2001:DB8:1111:3::9
2001:DB8:1111:3::2
PC1
G0/0
R1
S0/0/1
S0/1/0
R2
G0/0
PC2
F0/1
2001:DB8:1111:4::1
2001:DB8:1111:4::3
F0/0
ISP

Figure 26-13. Example Static IPv6 Addresses Based on the Subnet Design of Figure 26-12

This chapter puts off the details of how to configure the IPv6 addresses until the next two chapters. Chapter 27, "Implementing IPv6 Addressing on Routers," looks at how to configure IPv6 addresses on routers, with both static configuration and dynamic configuration. Chapter 28, "Implementing IPv6 Addressing on Hosts," examines how to configure hosts with IPv6 addresses, with more focus on the dynamic methods and the related protocols.

Unique Local Unicast Addresses

Unique local unicast addresses act as private IPv6 addresses. These addresses have many similarities with global unicast addresses, particularly in how to subnet. The biggest difference lies in the literal number (unique local addresses begin with hex FD), and with the administrative process: The unique local prefixes are not registered with any numbering authority, and can be used by multiple organizations.

Although the network engineer creates unique local addresses without any registration or assignment process, the addresses still need to follow some rules, as follows:

Key Topic

- Use FD as the first two hex digits.
- Choose a unique 40-bit global ID.
- Append the global ID to "FD" to create a 48-bit prefix, used as the prefix for all your addresses.
- Use the next 16 bits as a subnet field.
- Note that the structure leaves a convenient 64-bit interface ID field.

Figure 26-14 shows the format of these unique local unicast addresses.

Key Topic

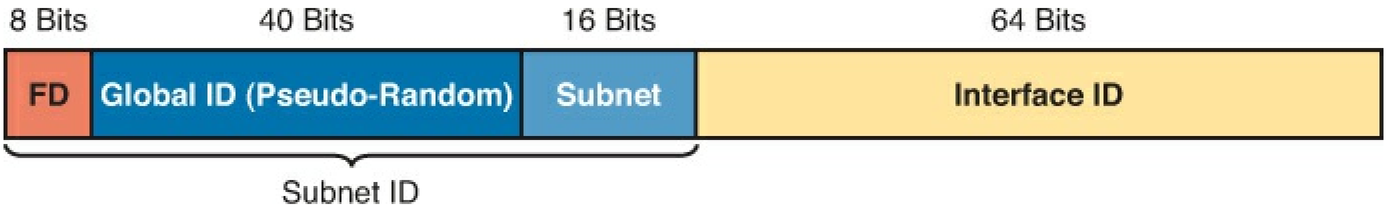

8 Bits
40 Bits
16 Bits
64 Bits
FD
Global ID (Pseudo-Random)
Subnet
Interface ID
Subnet ID

Figure 26-14. IPv6 Unique Local Unicast Address Format

> **Note**
>
> Just to be completely exact, IANA actually reserves prefix FC00::/7, and not FD00::/8, for these addresses. FC00::/7 includes all addresses that begin with hex FC and FD. However, an RFC (4193)

requires that the eighth bit of these addresses to be set to 1, so in practice today, the unique local addresses all begin with their first two digits as FD.

Subnetting with Unique Local IPv6 Addresses

Subnetting using unique local addresses works just like subnetting with global unicast addresses with a 48-bit global routing prefix. The only difference is that with global unicasts, you start by asking for a global routing prefix to be assigned to your company, and that global routing prefix might or might not have a *48 prefix length. With unique local, you create that prefix locally, and the prefix begins with* 48, with the first 8 bits set and the next 40 bits randomly chosen.

The process can be as simple as choosing a 40-bit value as your global ID. 40 bits requires 10 hex digits, so you can even avoid thinking in binary, and just make up a unique 10-hex-digit value. For example, imagine you chose a 40-bit global ID of 00 0001 0001. Your addresses must begin with the two hex digits FD, making the entire prefix be FD00:0001:0001::/48, or FD00:1:1::/48 when abbreviated.

To create subnets, just as you did in the earlier examples with a 48-bit global routing prefix, treat the entire fourth quartet as a subnet field, as shown in Figure 26-14.

Figure 26-15 shows an example subnetting plan using unique local addresses. The example repeats the same topology shown earlier in Figure 26-12; that figure showed subnetting with a global unicast prefix. This example uses the exact same numbers for the fourth quartet's subnet field, simply replacing the 48-bit global unicast prefix with this new local unique prefix of FD00:1:1.

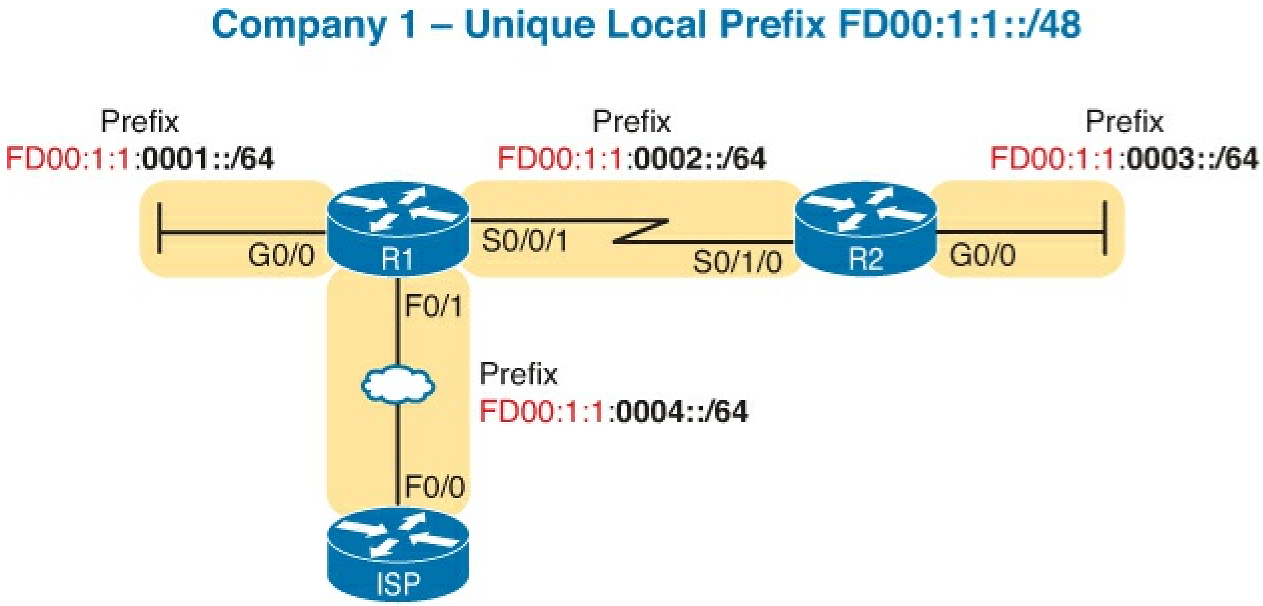


Figure 26-15. Subnetting Using Unique Local Addresses

The Need for Globally Unique Local Addresses

The example in Figure 26-15 shows an easy-to-remember prefix of FD00:1:1::/48. Clearly, I made up the easy-to-remember global ID in this example. What global ID would you choose for your company? Would you pick a number that you could not abbreviate, and make it shorter? If you had to pick the IPv6 prefix for you unique local addresses from the options in following list, which would you pick for your company?

- FDE9:81BE:A059::/48
- FDF0:E1D2:C3B4::/48
- FD00:1:1::/48

Given freedom to choose, most people would pick an easy-to-remember, short-to-type prefix, like FD00:1:1::/48. And in a lab or other small network used for testing, making up an easy to use number is reasonable. However, for use in real corporate networks, you should not just make up any global ID you like—you should try and follow the unique local address rules that strive to help make your addresses unique in the universe—even without registering a prefix with an ISP or RIR.

RFC 4193 defines unique local addresses. Part of that RFC stresses the importance of choosing your global ID in a way to make it statistically unlikely to be used by other companies. What is the result of unique global IDs at every company? Making all these unique local addresses unique across the globe. So if you do plan on using unique local addresses in a real network, plan on using the random number generator logic listed in RFC 4193 to create your prefix.

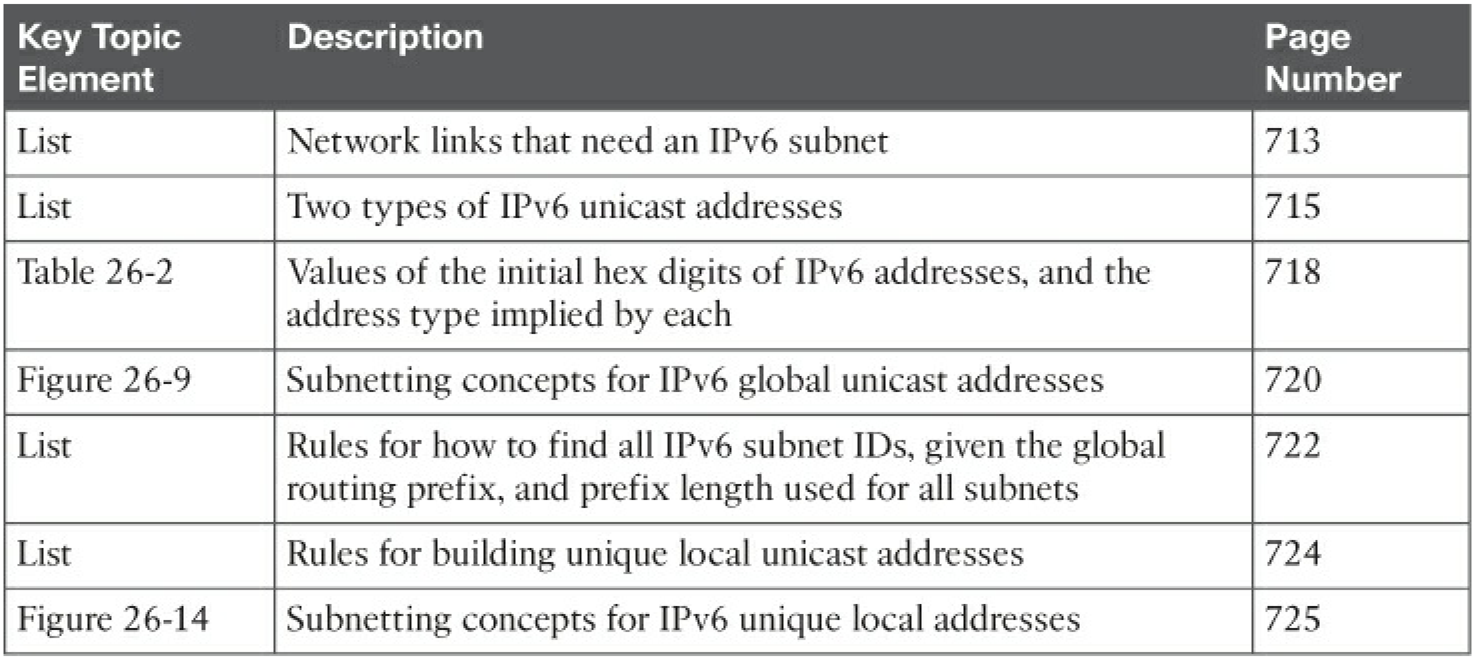
One of the big reasons to attempt to use a unique prefix, rather than everyone using the same easy-to-remember prefixes, is to be ready for the day that your company merges with or buys another company. Today, with IPv4, a high percentage of companies use private IPv4 network 10.0.0.0. When they merge their networks, the fact that both use network 10.0.0.0 makes the network merger more painful than if the companies had used different private IPv4 networks. With IPv6 unique local addresses, if both companies did the right thing, and randomly chose a prefix, they will most likely be using completely different prefixes, making the merger much simpler. However, companies that take the seemingly easy way out, and choose an easy-to-remember prefix like of FD00:1:1, greatly increase their risk of requiring extra effort when merging with another company that also chose to use that same prefix.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 26-3 lists these key topics and where each is discussed.

Table 26-3. Key Topics for Chapter 26



Key Topic Element	Description	Page Number
List	Network links that need an IPv6 subnet	713
List	Two types of IPv6 unicast addresses	715
Table 26-2	Values of the initial hex digits of IPv6 addresses, and the address type implied by each	718
Figure 26-9	Subnetting concepts for IPv6 global unicast addresses	720
List	Rules for how to find all IPv6 subnet IDs, given the global routing prefix, and prefix length used for all subnets	722
List	Rules for building unique local unicast addresses	724
Figure 26-14	Subnetting concepts for IPv6 unique local addresses	725

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists for you to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

- global unicast address
- global routing prefix
- unique local address
- subnet ID (prefix ID)
- subnet router anycast address

Chapter 27. Implementing IPv6 Addressing on Routers

This chapter covers the following exam topics:

- **IP addressing (IPv4 / IPv6)**
  - Describe the technological requirements for running IPv6 in conjunction with IPv4 such as dual stack
  - Describe IPv6 addresses
    - Multicast
    - Link local
    - eui 64
- **IP Routing Technologies**
  - Configure and verify utilizing the CLI to set basic Router configuration
    - Cisco IOS commands to perform basic router setup
  - Configure and verify operation status of an ethernet interface
  - Verify router configuration and network connectivity
    - Cisco IOS commands to review basic router information and network connectivity
- **Troubleshooting**
  - Troubleshoot and correct common problems associated with IP addressing and host configurations.

With IPv4 addressing, some devices, like servers and routers, typically use static predefined IPv4 addresses. End-user devices do not mind if their address changes from time to time, and they typically learn an IPv4 address dynamically using DHCP. IPv6 uses the same general mode, with servers, routers, and other devices in the control of the IT group often using predefined IPv6 addresses, and with end-user devices using dynamically learned IPv6 addresses.

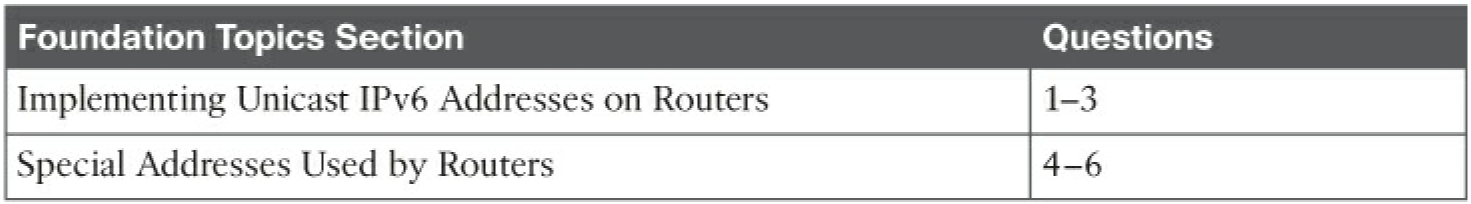
This chapter focuses on the addresses configured on routers, while Chapter 28, "Implementing IPv6 Addressing on Hosts," focuses on the addresses learned by IPv6 hosts.

Routers require unicast IPv6 addresses on their interfaces. At the same time, routers use a variety of other IPv6 addresses to participate in many of the protocols and roles required of a router. This chapter begins with the more obvious IPv6 addressing configuration, with features that mirror IPv4 features, showing how to configure interfaces with IPv6 addresses and view that configuration with **show** commands. The second half of the chapter introduces new IPv6 addressing concepts, showing some other addresses used by routers when doing different tasks.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 27-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Implementing Unicast IPv6 Addresses on Routers	1–3
Special Addresses Used by Routers	4–6

1. Router R1 has an interface named Gigabit Ethernet 0/1, whose MAC address has been set to 0200.0001.000A. Which of the following commands, added in R1's Gigabit Ethernet 0/1 configuration mode, gives this router's G0/1 interface a unicast IPv6 address of 2001:1:1:1:1:200:1:A, with a /64 prefix length?
   a. ipv6 address 2001:1:1:1:1:200:1:A/64
   b. ipv6 address 2001:1:1:1:1:200:1:A/64 eui-64
   c. ipv6 address 2001:1:1:1:1:200:1:A /64 eui-64
   d. ipv6 address 2001:1:1:1:1:200:1:A /64
   e. None of the other answers are correct.
2. Router R1 has an interface named Gigabit Ethernet 0/1, whose MAC address has been set to 5055.4444.3333. This interface has been configured with the **ipv6 address 2000:1:1:1::/64 eui-64** subcommand. What unicast address will this interface use?
   a. 2000:1:1:1:52FF:FE55:4444:3333
   b. 2000:1:1:1:5255:44FF:FE44:3333
   c. 2000:1:1:1:5255:4444:33FF:FE33
   d. 2000:1:1:1:200:FF:FE00:0

3. Router R1 currently supports IPv4, routing packets in and out all its interfaces. R1’s configuration needs to be migrated to support dual-stack operation, routing both IPv4 and IPv6. Which of the following tasks must be performed before the router can also support routing IPv6 packets? (Choose two answers.)

- **a.** Enable IPv6 on each interface using an **ipv6 address** interface subcommand.
- **b.** Enable support for both versions with the **ip versions 4 6** global command.
- **c.** Additionally enable IPv6 routing using the **ipv6 unicast-routing** global command.
- **d.** Migrate to dual-stack routing using the **ip routing dual-stack** global command.

4. Router R1 has an interface named Gigabit Ethernet 0/1, whose MAC address has been set to 0200.0001.000A. The interface is then configured with the **ipv6 address 2001:1:1:1:200:FF:FE01:B/64** interface subcommand; no other **ipv6 address** commands are configured on the interface. Which of the following answers lists the link-local address used on the interface?

- **a. FE80::FF:FE01:A**
- **b. FE80::FF:FE01:B**
- **c. FE80::200:FF:FE01:A**
- **d. FE80::200:FF:FE01:B**

5. Which of the following multicast addresses is defined as the address for sending packets to only the IPv6 routers on the local link?

- **a.** FF02::1
- **b.** FF02::2
- **c.** FF02::5
- **d.** FF02::A

6. Router R1 has an interface named Gigabit Ethernet 0/1, whose MAC address has been set to 0200.0001.000A. Which of the following commands, added in R1’s Gigabit Ethernet 0/1 configuration mode, results in R1 using a solicited node multicast address of FF02::1:FF00:A?

- **a. ipv6 address 2001:1:1:1:1:200:1:A/64**
- **b. ipv6 address 2001:1:1:1::/64 eui-64**
- **c. ipv6 address 2001:1:1:1::A/64**
- **d.** None of the other answers results in R1 using that multicast address.

Answers to the “Do I Know This Already?” quiz:

1 A **2** B **3** A and C **4** A **5** B **6** C

Foundation Topics

Implementing Unicast IPv6 Addresses on Routers

Every company bases its enterprise network on one or more protocol models, or protocol stacks. In the earlier days of networking, enterprise networks used one or more protocol stacks from different vendors, as shown on the left of Figure 27-1. Over time, companies added TCP/IP (based on IPv4) to the mix. Eventually, companies migrated fully to TCP/IP as the only protocol stack in use.

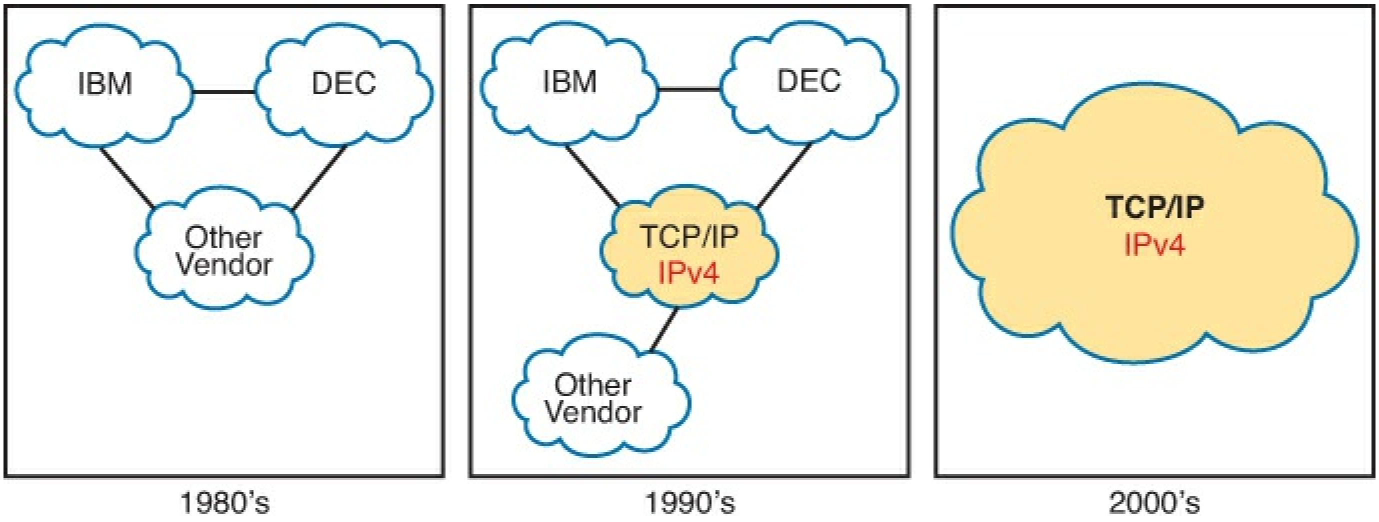


Figure 27-1. Migration of Enterprise Networks to Use TCP/IP Stack Only, IPv4

The emergence of IPv6 requires that IPv6 be implemented in end-user hosts, servers, routers, and other devices. However, corporations cannot just migrate all devices from IPv4 to IPv6 over one weekend. Instead, what will likely occur is some kind of long-term migration and coexistence, in which for a large number of years, most corporate networks again use multiple protocol stacks: one based on IPv4 and one based on IPv6.

Eventually, over time, we might all see the day when enterprise networks run only IPv6, without any IPv4 remaining, but that day might take a while. Figure 27-2 shows the progression, just to make the point, but who knows how long it will take?

Key Topic

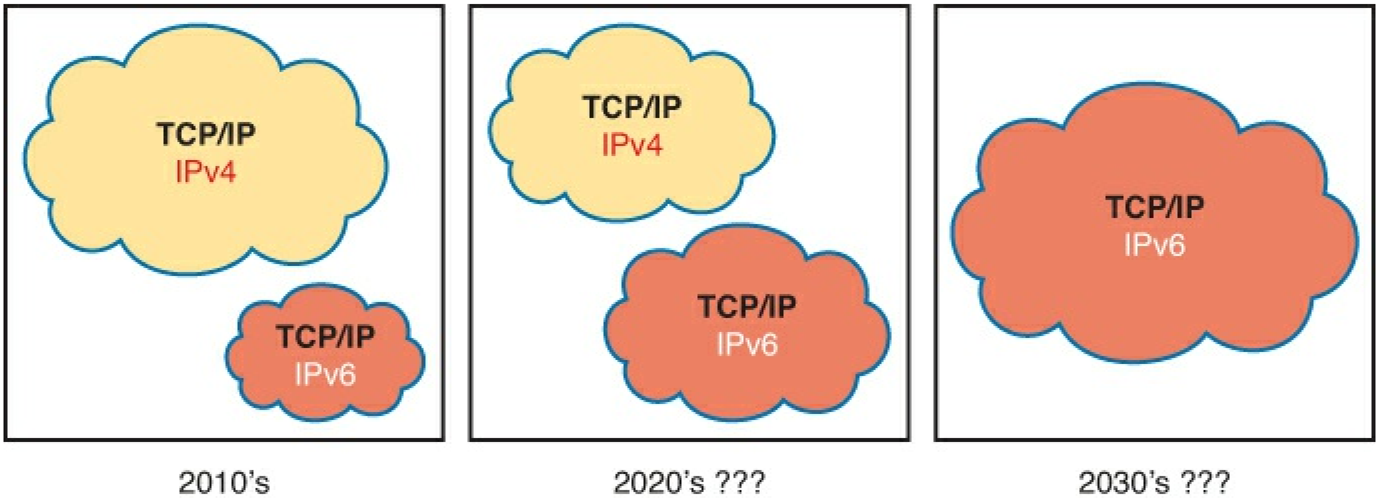


Figure 27-2. Likely Path Through Dual-Stack (IPv4 and IPv6) over a Long Period

One way to add IPv6 support to an established IPv4-based enterprise internetwork is to implement a dual-stack strategy. To do so, the routers can be configured to route IPv6 packets, with IPv6 addresses on their interfaces, with a similar model to how routers support IPv4. Then, hosts can implement IPv6 when ready, running both IPv4 and IPv6 (dual stacks). The first major section of this chapter shows how to configure and verify unicast IPv6 addresses on routers.

Static Unicast Address Configuration

Cisco routers give us two options for static configuration of IPv6 addresses. In one case, you configure the full 128-bit address, while in the other, you configure a 64-bit prefix, and let the router derive the second half of the address (the interface ID). The next few pages show how to configure both options, and how the router chooses the second half of the IPv6 address.

Configuring the Full 128-Bit Address

To statically configure the full 128-bit unicast address—either global unicast or unique local—the router needs an **ipv6 address** *address/prefix-length* interface subcommand on each interface. The address can be an abbreviated IPv6 address, or the full 32-digit hex address. The command includes the prefix length value, at the end, with no space between the address and prefix length.

The configuration of the router interface IPv6 address really is that simple. Figure 27-3, along with Examples 27-1 and 27-2, shows a basic example. The figure shows the global unicast IPv6 address used by two different routers, on two interfaces each. As usual, all subnets use a /64 prefix length.

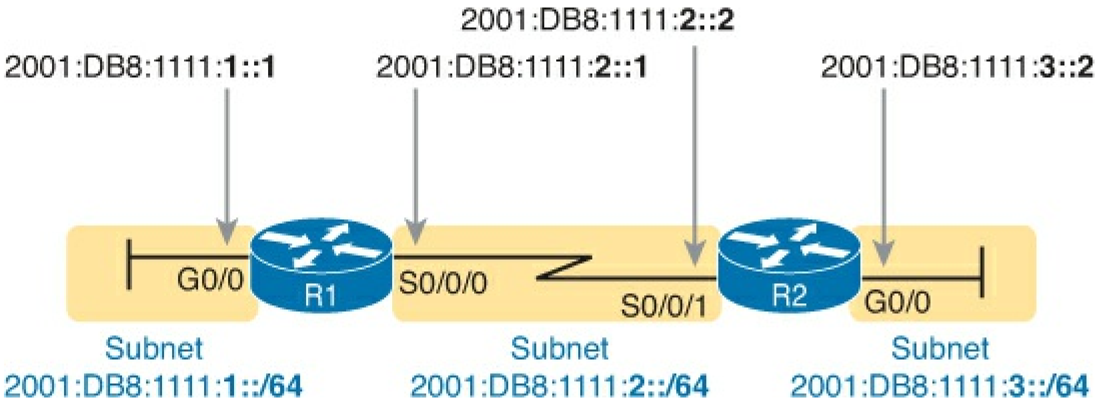


Figure 27-3. 128-bit IPv6 Addresses to Be Configured on Cisco Router Interfaces

Example 27-1. Configuring Static IPv6 Addresses on R1

Click here to view code image

```
ipv6 unicast-routing
!
interface GigabitEthernet0/0
ipv6 address 2001:DB8:1111:1::1/64
!
interface Serial0/0/0
ipv6 address 2001:0db8:1111:0002:0000:0000:0000:0001/64
```

Example 27-2. Configuring Static IPv6 Addresses on R2

```
ipv6 unicast-routing
!
interface GigabitEthernet0/0
ipv6 address 2001:DB8:1111:3::2/64
!
interface Serial0/0/1
ipv6 address 2001:db8:1111:2::2/64
```

Note

Example 27-1's configuration on R1 uses both abbreviated and unabbreviated addresses, and both lowercase and uppercase hex digits, showing that all are allowed. Router **show** commands list the abbreviated value with uppercase hex digits.

Enabling IPv6 Routing

While the configuration shown in Examples 27-1 and 27-2 focus on the IPv6 address configuration, they also include an important but often overlooked step when configuring IPv6 on Cisco routers: IPv6 routing needs to be enabled.

Before routers can route (forward) IPv6 packets, IPv6 routing must be enabled. On Cisco routers, IPv4 routing is enabled by default, but IPv6 routing is not enabled by default. The solution takes only a single command—**ipv6 unicast-routing**—which enables IPv6 routing on the router.

Note that a router must enable IPv6 globally (**ipv6 unicast-routing**) and enable IPv6 on the interface (**ipv6 address**), before the router will attempt to route packets in and out an interface. (If the router happens to omit the **ipv6 unicast-routing** command, it can still be configured with interface IPv6 addresses, but the router acts like an IPv6 host, and does not route IPv6 packets.)

Verifying the IPv6 Address Configuration

IPv6 uses many **show** commands that mimic the syntax of IPv4 **show** commands. For example:

- The **show ipv6 interface brief** command gives you interface IPv6 address info, but not prefix length info, similar to the IPv4 **show ip interface brief** command.
- The **show ipv6 interface** command gives the details of IPv6 interface settings, much like the **show ip interface**

command does for IPv4.

The one notable difference in the most common commands is that the **show interfaces** command still lists the IPv4 address and mask, but tells us nothing about IPv6. So, to see IPv6 interface addresses, use commands that begin with **show ipv6**. Example 27-3 lists a few samples from Router R1, with the explanations following.

Example 27-3. Verifying Static IPv6 Addresses on Router R1

Click here to view code image

```
! The first interface is in subnet 1
R1# show ipv6 interface GigabitEthernet 0/0
GigabitEthernet0/0 is up, line protocol is up
IPv6 is enabled, link-local address is FE80::1FF:FE01:101
No Virtual link-local address(es):
Description: LAN at Site 1
Global unicast address(es):
2001:DB8:1111:1::1, subnet is 2001:DB8:1111:1::/64
Joined group address(es):
FF02::1
FF02::2
FF02::A
FF02::1:FF00:1
FF02::1:FF01:101
MTU is 1500 bytes
ICMP error messages limited to one every 100 milliseconds
ICMP redirects are enabled
ICMP unreachables are sent
ND DAD is enabled, number of DAD attempts: 1
ND reachable time is 30000 milliseconds (using 30000)
ND advertised reachable time is 0 (unspecified)
ND advertised retransmit interval is 0 (unspecified)
ND router advertisements are sent every 200 seconds
ND router advertisements live for 1800 seconds
ND advertised default router preference is Medium
Hosts use stateless autoconfig for addresses.

R1# show ipv6 interface S0/0/0
Serial0/0/0 is up, line protocol is up
IPv6 is enabled, link-local address is FE80::1FF:FE01:101
No Virtual link-local address(es):
Description: link to R2
Global unicast address(es):
2001:DB8:1111:2::1, subnet is 2001:DB8:1111:2::/64
Joined group address(es):
FF02::1
FF02::2
FF02::A
FF02::1:FF00:1
FF02::1:FF01:101
MTU is 1500 bytes
! Lines omitted for brevity

R1# show ipv6 interface brief
GigabitEthernet0/0 [up/up]
FE80::1FF:FE01:101
2001:DB8:1111:1::1
GigabitEthernet0/1 [administratively down/down]
unassigned
Serial0/0/0 [up/up]
FE80::1FF:FE01:101
2001:DB8:1111:2::1
Serial0/0/1 [administratively down/down]
unassigned
```

First, focus on the output of the two **show ipv6 interface** commands that make up most of the output in Example 27-3. The first command lists interface G0/0, showing output about that interface only. Note that the output lists the configured IPv6 address and prefix length, as well as the IPv6 subnet (2001:DB8:1111:1::/64), which the router calculated based on the IPv6 address. The second **show ipv6 interface** command shows similar details for interface S0/0/0, with some of the volume of output omitted.

The end of the example lists the output of the **show ipv6 interface brief** command. Similar to the IPv4-focused **show ip interface brief** command, this command lists IPv6 addresses, but not the prefix length or prefixes. This command also lists all interfaces on the router, whether or not IPv6 is enabled on the interfaces. For example, in this case, the only two interfaces on R1 that have an IPv6 address are G0/0 and S0/0/0, as configured earlier in Example 27-1.

Beyond the IPv6 addresses on the interfaces, the router also adds IPv6 connected routes to the IPv6 routing table off each interface. Just as with IPv4, the router keeps these connected routes in the IPv6 routing table only when the interface is in a working (up/up) state. But if the interface has an IPv6 unicast address configured, and the interface is working, the router adds the connected routes. Example 27-4 shows the connected IPv6 on Router R1 from Figure 27-3.

Example 27-4. Displaying Connected IPv6 Routes on Router R1

Click here to view code image

```
R1# show ipv6 route connected
IPv6 Routing Table - default - 5 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
B - BGP, R - RIP, I1 - ISIS L1, I2 - ISIS L2
IA - ISIS interarea, IS - ISIS summary, D - EIGRP, EX - EIGRP external
ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
C 2001:DB8:1111:1::/64 [0/0]
via GigabitEthernet0/0, directly connected
C 2001:DB8:1111:2::/64 [0/0]
via Serial0/0/0, directly connected
```

Generating a Unique Interface ID Using EUI-64

IPv6 follows the same general model as IPv4 regarding which types of devices typically use static, predefined addresses, and which use dynamically learned address. For example, routers inside an enterprise use a static IPv4 addresses, while end-user devices typically learn their IPv4 address using DHCP. With IPv6, routers also typically use static IPv6 addresses, while user devices use DHCP or Stateless Address Auto Configuration (SLAAC) to dynamically learn their IPv6 address.

Interestingly, routers have two options for configuring a stable and predictable IPv6 interface address that does not change. One method, discussed already in this chapter, uses the **ipv6 address** command to define the entire 128-bit address, as shown in Examples 27-1 and 27-2. The other method uses this same **ipv6 address** command to configure only the 64-bit IPv6 prefix for the interface, and lets the router automatically generate a unique interface ID.

This second method uses rules called EUI-64 (extended unique identifier). The configuration includes a keyword to tell the router to use EUI-64 rules, along with the 64-bit prefix. The router then uses EUI-64 rules to create the interface ID part of the address, as follows:

Key Topic

1. Split the 6-byte (12-hex-digit) MAC address in two halves (6 hex digits each).
2. Insert FFFE in between the two, making the interface ID now have a total of 16 hex digits (64 bits).
3. Invert the seventh bit of the interface ID.

Figure 27-4 shows the major pieces of how the address is formed.

Key Topic

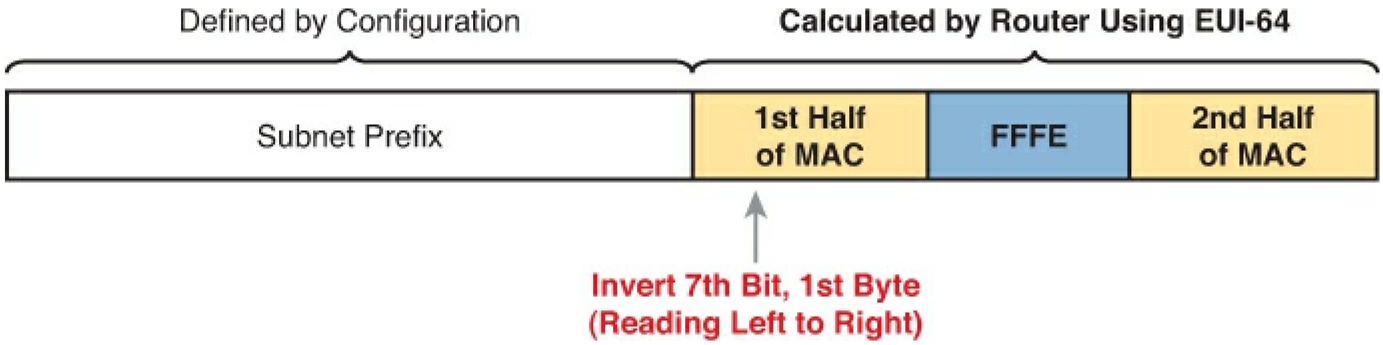

Defined by Configuration
Calculated by Router Using EUI-64
Subnet Prefix
1st Half of MAC
FFFE
2nd Half of MAC
Invert 7th Bit, 1st Byte (Reading Left to Right)

Figure 27-4. IPv6 Address Format with Interface ID and EUI-64

Although it might seem a bit convoluted, it works. Also, with a little practice, you can look at an IPv6 address and quickly notice the FFFE in the middle of the interface ID, and then easily find the two halves of the corresponding interface's MAC address. But you need to be ready to do the same math, in this case to predict the EUI-64 formatted IPv6 address on an interface.

For example, if you ignore the final step of inverting the seventh bit, the rest of the steps just require that you move the pieces around. Figure 27-5 shows two examples, just so you see the process.

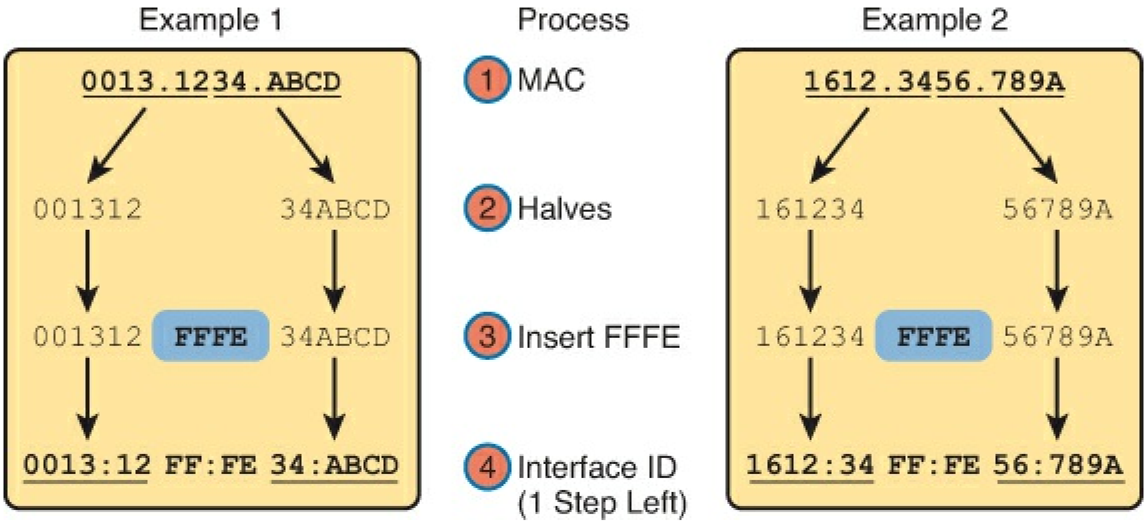

Example 1
Process
Example 2
0013.1234.ABCD
① MAC
1612.3456.789A
001312
34ABCD
② Halves
161234
56789A
001312 FFFE 34ABCD
③ Insert FFFE
161234 FFFE 56789A
0013:12 FF:FE 34:ABCD
④ Interface ID (1 Step Left)
1612:34 FF:FE 56:789A

Figure 27-5. Two Examples of Most of the EUI-64 Interface ID Process

Both examples follow the same process. Each starts with the MAC address, breaking it into two halves (Step 2). The third step inserts FFFE in the middle, and the fourth step inserts a colon every four hex digits, keeping with IPv6 conventions.

While the examples in Figure 27-5 show most of the steps, they omit the final step. The final step requires that you convert the first byte (first two hex digits) from hex to binary, invert the seventh of the 8 bits, and convert the bits back to binary. Inverting a bit means that if the bit is a 0, make it a 1; if it is a 1, make it a 0. Most of the time, with IPv6 addresses, the original bit will be 0, and will be inverted to a 1.

> **Note**
>
> The bit being inverted for EUI-64 is called the universal/local bit, with a value of 0 meaning that the MAC is a universal burned-in address. All burned-in MAC addresses should have a binary 0 in this bit position. Because people seldom override their router MAC addresses, the EUI-64 calculation will typically change the seventh bit from a binary 0 to a binary 1.

For example, Figure 27-6 completes the two examples from Figure 27-5, focusing only on the first two hex digits. The examples show each pair of hex digits (Step 1) and the binary equivalent (Step 2). Step 3 shows a copy of those same 8 bits, except the seventh bit is inverted; the example on the left inverts from 0 to 1, and the example on the right inverts from 1 to 0. Finally, the bits are converted back to hex at Step 4.

Key Topic

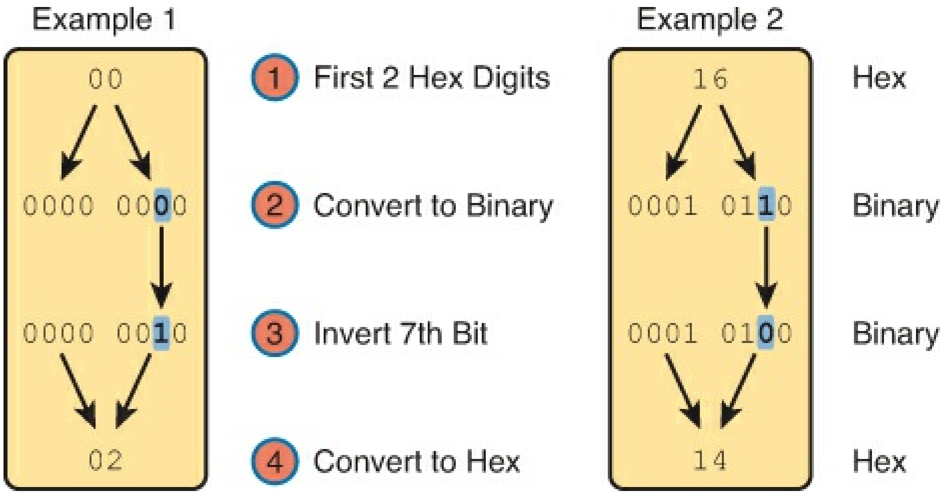

Example 1
Example 2
00
① First 2 Hex Digits
16
Hex
0000 0000
② Convert to Binary
0001 0110
Binary
0000 0010
③ Invert 7th Bit
0001 0100
Binary
02
④ Convert to Hex
14
Hex

Figure 27-6. Inverting the Seventh Bit of an EUI-64 Interface ID Field

> **Note**

If you do not remember how to do hex to binary conversions, take a few moments to review the process. If you memorize the 16 hex values for digits 0 through F, with the corresponding binary values, the conversion can be easy. If you do not have those handy in your memory, take a few moments to look at Table A-2 in Appendix A, "Numeric Reference Tables."

As usual, the best way to get comfortable with forming these EUI-64 interface IDs is to calculate some yourself. Table 27-2 lists some practice problems, with an IPv6 64-bit prefix in the first column and the MAC address in the second column. Your job is to calculate the full (unabbreviated) IPv6 address using EUI-64 rules. The answers sit at the end of the chapter, in the section "Answers to Earlier Practice Problems."

Table 27-2. IPv6 EUI-64 Address Creation Practice

Prefix	MAC Address	Unabbreviated IPv6 Address
2001:DB8:1:1::/64	0013.ABAB.1001	
2001:DB8:1:1::/64	AA13.ABAB.1001	
2001:DB8:1:1::/64	000C.BEEF.CAFE	
2001:DB8:1:1::/64	B80C.BEEF.CAFE	
2001:DB8:FE:FE::/64	0C0C.ABAC.CABA	
2001:DB8:FE:FE::/64	0A0C.ABAC.CABA	

Configuring a router interface to use the EUI-64 format uses the **ipv6 address** *address/prefix-length* **eui-64** interface subcommand. The **eui-64** keyword tells the router to find the interface MAC address and do the EUI-64 conversion math to find the interface ID.

Example 27-5 shows a revised configuration on Router R1, as compared to the earlier Example 27-1. In this case, R1 uses EUI-64 formatting for its IPv6 addresses.

Example 27-5. Configuring R1's IPv6 Interfaces Using EUI-64

Click here to view code image

```
! The next commands are on router R1
ipv6 unicast-routing
!
! The ipv6 address command now lists the a prefix
interface GigabitEthernet0/0
ipv6 address 2001:DB8:1111:1::/64 eui-64
!
interface Serial0/0/0
ipv6 address 2001:DB8:1111:2::/64 eui-64

R1# show ipv6 interface brief
GigabitEthernet0/0 [up/up]
FE80::1FF:FE01:101
2001:DB8:1111:1:0:1FF:FE01:101
GigabitEthernet0/1 [administratively down/down]
unassigned
Serial0/0/0 [up/up]
FE80::1FF:FE01:101
2001:DB8:1111:2:0:1FF:FE01:101
Serial0/0/1 [administratively down/down]
unassigned
```

Note that the example shows EUI-64 being used on a serial interface, which does not have an associated MAC address. For interfaces that do not have a MAC address, the router chooses the MAC of the lowest-numbered router interface that does have a MAC. In this example, R1 uses its G0/0 interface MAC to form the EUI-64 interface ID for all the serial interfaces.

Note

When using EUI-64, the address value in the **ipv6 address** command should be the prefix, not the full 128-bit IPv6 address. However, if you mistakenly type the full address, and still use the **eui-64** keyword, IOS accepts the command, and converts the address to the matching prefix before putting the command into the running config file. For example, IOS accepts and then converts the **ipv6 address 2000:1:1:1::1/64 eui-64** command to **ipv6 address 2000:1:1:1::/64 eui-64**.

Dynamic Unicast Address Configuration

In most cases, network engineers will configure the IPv6 addresses of router interfaces so that the addresses do not change until the engineer changes the router configuration. However, routers can be configured to use dynamically learned IPv6 addresses. These can be useful for routers connecting to the Internet through some types of Internet access technologies, like DSL and cable modems.

Cisco routers support two ways for the router interface to dynamically learn an IPv6 address to use:

- Stateful DHCP
- Stateless Address Autoconfiguration (SLAAC)

Both methods use the familiar **ipv6 address** command. Of course, neither option configures the actual IPv6 address; instead, the commands configure a keyword that tells the router which method to use to learn its IPv6 address. Example 27-6 shows the configuration, with one interface using stateful DHCP, and one using SLAAC.

Example 27-6. Router Configuration to Learn IPv6 Addresses with DHCP and SLAAC

Click here to view code image

```
! This interface uses DHCP to learn its IPv6 address
interface FastEthernet0/0
ipv6 address dhcp
!
! This interface uses SLAAC to learn its IPv6 address
interface FastEthernet0/1
ipv6 address autoconfig
```

Cisco routers also have to be ready to play a role with DHCP and SLAAC on behalf of other IPv6 devices in the network. Chapter 28, which focuses on implementing IPv6 on hosts, discusses the protocols and the responsibilities of the routers.

Special Addresses Used by Routers

IPv6 configuration on a router begins with the simple steps discussed in the first part of this chapter. After configuring the **ipv6 unicast-routing** global configuration command, to enable the function of IPv6 routing, the addition of a unicast IPv6 address on an interface causes the router to do the following:

Key Topic

- Gives the interface a unicast IPv6 address
- Enables the routing of IPv6 packets in/out that interface
- Defines the IPv6 prefix (subnet) that exists off that interface
- Tells the router to add a connected IPv6 route for that prefix, to the IPv6 routing table, when that interface is up/up

Note

In fact, if you pause and look at the list again, the same ideas happen for IPv4 when you configure an IPv4 address on a router interface.

While all the IPv6 features in this list work much like similar features in IPv4, IPv6 also has a number of additional functions not seen in IPv4. Often, these additional functions use other IPv6 addresses, many of which are multicast addresses. This second major section of this chapter examines the additional IPv6 addresses seen on routers, with a brief description of how they are used.

Link-Local Addresses

IPv6 uses link-local addresses as a special kind of unicast IPv6 address. These addresses are not used for normal IPv6 packet flows that contain data for applications. Instead, these addresses are used by some overhead protocols and for routing. This next topic first looks at how IPv6 uses link-local addresses and then how routers create link-local addresses.

Link-Local Address Concepts

Each IPv6 host (routers included) use an additional unicast address called a link-local address. Packets sent to a link-local address do not leave the IPv6 subnet, because routers do not forward packets sent to a link-local address.

IPv6 uses link-local addresses for a variety of protocols. Many IPv6 protocols that need to send messages inside a single subnet typically use link-local addresses, rather than the host's global unicast or unique local address. For example, Neighbor Discovery Protocol (NDP), which replaces the functions of IPv4's ARP, uses link-local addresses.

Routers also use link-local addresses as the next-hop IP addresses in IPv6 routes, as shown in Figure 27-7. IPv6 hosts also use a default router (default gateway) concept, like IPv4, but instead of the router address being in the same subnet, hosts refer to the router's link-local address. The **show ipv6 route** command lists the link-local address of the neighboring router, and not the global unicast or unique local unicast address.

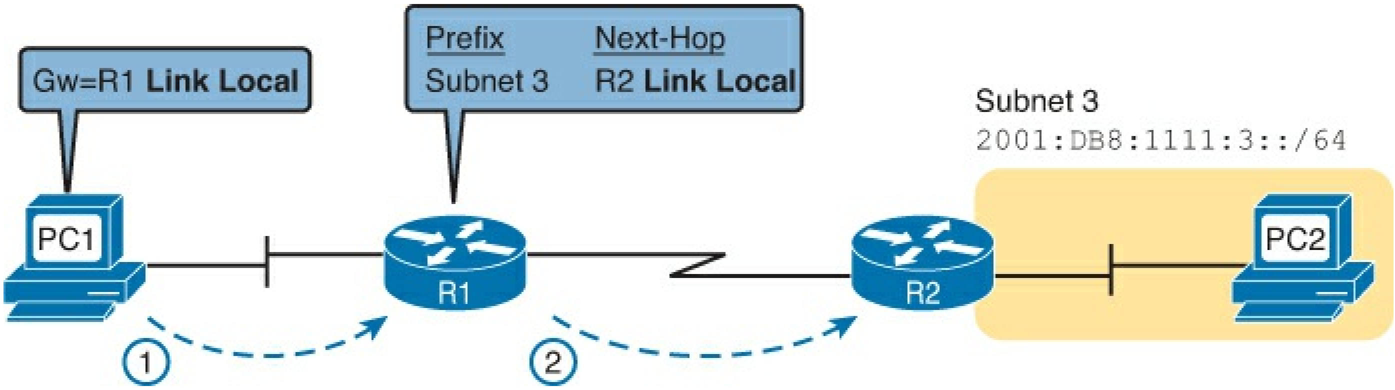


Figure 27-7. IPv6 Using Link-Local Addresses as the Next-Hop Address

The following list summarizes the key facts about link-local addresses:

Key Topic

Unicast (not multicast): Link-local addresses represent a single host, and packets sent to a link-local address should be processed by only that one IPv6 host.

Forwarding scope is the local link only: Packets sent to a link-local address do not leave the local data link, because routers do not forward packets with link-local destination addresses.

Automatically generated: Every IPv6 host interface (and router interface) can create their own link-local address automatically, solving some initialization problems for hosts before they learn a dynamically learned global unicast address.

Common uses: Used for some overhead protocols that stay local to one subnet, and as the next-hop address for IPv6 routes.

Creating Link-Local Addresses on Routers

IPv6 hosts and routers can calculate their own link-local address, for each interface, using some basic rules. First, all link-local addresses start with the same prefix, as shown on the left side of Figure 27-8. By definition, the first 10 bits must match prefix FE80::/10, meaning that the first three hex digits will be either FE8, FE9, FEA, or FEB. However, when following the RFC, the next 54 bits should be binary 0, so the link-local address should always start with FE80:0000:0000:0000 as the first four unabbreviated quartets.

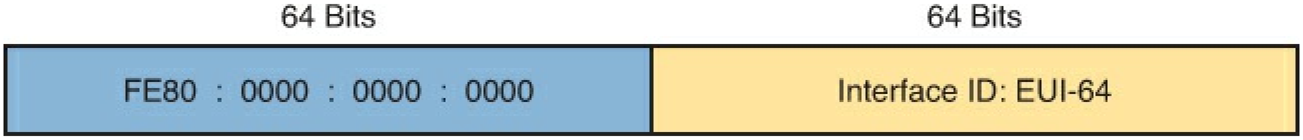


Figure 27-8. Link-Local Address Format

The second half of the link-local address, in practice, can be formed with different rules. Cisco routers use the EUI-64 format to create the interface ID (see the earlier section "Generating a Unique Interface ID Using EUI-64"). As a result, a router's complete link-local address should be unique, because the MAC address that feeds into the EUI-64 process should be unique. Other OSs randomly generate the interface ID. For example, Microsoft OSs use a somewhat random process to choose the interface ID, and change it over time, in an attempt to prevent some forms of attacks. Finally, link-local addresses can simply be configured.

IOS creates a link-local address for any interface that has configured at least one other unicast address using the **ipv6 address** command (global unicast or unique local). To see the link-local address, just use the usual commands that also list the unicast IPv6 address: **show ipv6 interface** and **show ipv6 interface brief**. Example 27-7 shows an example from Router R1.

Example 27-7. Comparing Link-Local Addresses with EUI-Generated Unicast Addresses

Click here to view code image

```
R1# show ipv6 interface brief
GigabitEthernet0/0 [up/up]
```

```
FE80::1FF:FE01:101
2001:DB8:1111:1:0:1FF:FE01:101
GigabitEthernet0/1 [administratively down/down]
unassigned
Serial0/0/0 [up/up]
FE80::1FF:FE01:101
2001:DB8:1111:2:0:1FF:FE01:101
Serial0/0/1 [administratively down/down]
unassigned
```

First, examine the two pair of highlighted entries in the example. For each of the two interfaces that have a global unicast address (G0/0 and S0/0/0), the output lists the global unicast, which happens to begin with 2001 in this case. At the same time, the output also lists the link-local address for each interface, beginning with FE80.

Next, focus on the two addresses listed under interface G0/0. If you look closely at the second half of the two addresses listed for interface G0/0, you will see that both addresses have the same interface ID value. The global unicast address was configured in this case with the **ipv6 address 2001:DB8:1111:1::/64 eui-64** command, so the router used EUI-64 logic to form both the global unicast address and the link-local address. The interface MAC address in this case is 0200.0101.0101, so the router calculates an interface ID portion of both addresses as 0000:01FF:FE01:0101 (unabbreviated). After abbreviation, router R1's link-local address on interface G0/0 becomes FE80::1FF:FE01:101.

IOS can either automatically create the link-local address, or it can be configured. IOS chooses the link-local address for the interface based on the following rules:

- If configured, the router uses the value in the **ipv6 address** *address* **link-local** interface subcommand. Note that the configured link-local address must be from the correct address range for link-local addresses, that is, an address from prefix FE80::/10. In other words, the address must begin with FE8, FE9, FEA, or FEB.
- If not configured, the IOS calculates the link-local address using EUI-64 rules, as discussed and demonstrated in and around Example 27-7. The calculation uses EUI-64 rules even if the interface unicast address does not use EUI-64.

IPv6 Multicast Addresses

IPv6 uses multicast IPv6 addresses for several purposes. In some cases, overhead protocols use these addresses to send packets to multiple IPv6 hosts at once. In other cases, applications use multicast addresses to send IPv6 packets to many hosts, rather than sending a different packet to each individual host.

This next topic first compares the use of broadcast address with the use of multicast addresses. It then looks at some common multicast addresses used with IPv6.

Broadcasts Versus Multicasts

The terms *broadcast* and *multicast* have subtle and slightly different meanings. After you learn more about both, particularly multicasts, the differences become obvious. However, CCENT and CCNA R/S do not get into much depth on either topic, so briefly, take a moment to consider a basic comparison.

First, think about IPv4, and an IPv4 subnet. IPv4 uses broadcasts, meaning that IPv4 allows a host to send a packet to a broadcast address, such that all IPv4 hosts in that subnet must listen for the packet, read the packet, and at least spend some CPU cycles deciding whether they need to respond. In short, a broadcast goes to all devices, and all must consider the message.

Broadcasts can be wasteful of the CPU cycles on the hosts in a subnet, because oftentimes, a broadcast is used to get a response for only one host, or just a few hosts, in that subnet. Multicasts help solve that problem, by causing a packet to be processed only by the correct subset of hosts. Because using multicasts is more efficient for the devices in the network, IPv6 does not use broadcasts, instead using multicast addresses.

To complete the comparison, now think about IPv6, and an IPv6 subnet with 100 hosts and 3 routers. Sometimes, a host wants to send a packet to "all hosts running IPv6"—well, IPv6 defines a multicast address for that (FF02::1). Packets sent to FF02::1 arrive at all devices that have IPv6 enabled (including routers) and should be processed by all. However, if a protocol message needs to go to all IPv6 routers, but not to hosts, the packet can be sent to address FF02::2—a multicast address used only by IPv6 routers. Packets sent to FF02::2 do not require any processing by the nonrouters, saving their CPU cycles.

Continuing the comparison one step further, a packet could be sent to a subset of the routers. Enhanced Interior Gateway Routing Protocol (EIGRP) uses a reserved multicast address (FF02::A), while Open Shortest Path First (OSPF) uses two (FF02::5 and FF02::6). These routing protocols send their Update messages to these reserved multicast addresses, so a router running EIGRP does not bother a router running OSPF, or vice versa.

Common Local Scope Multicast Addresses

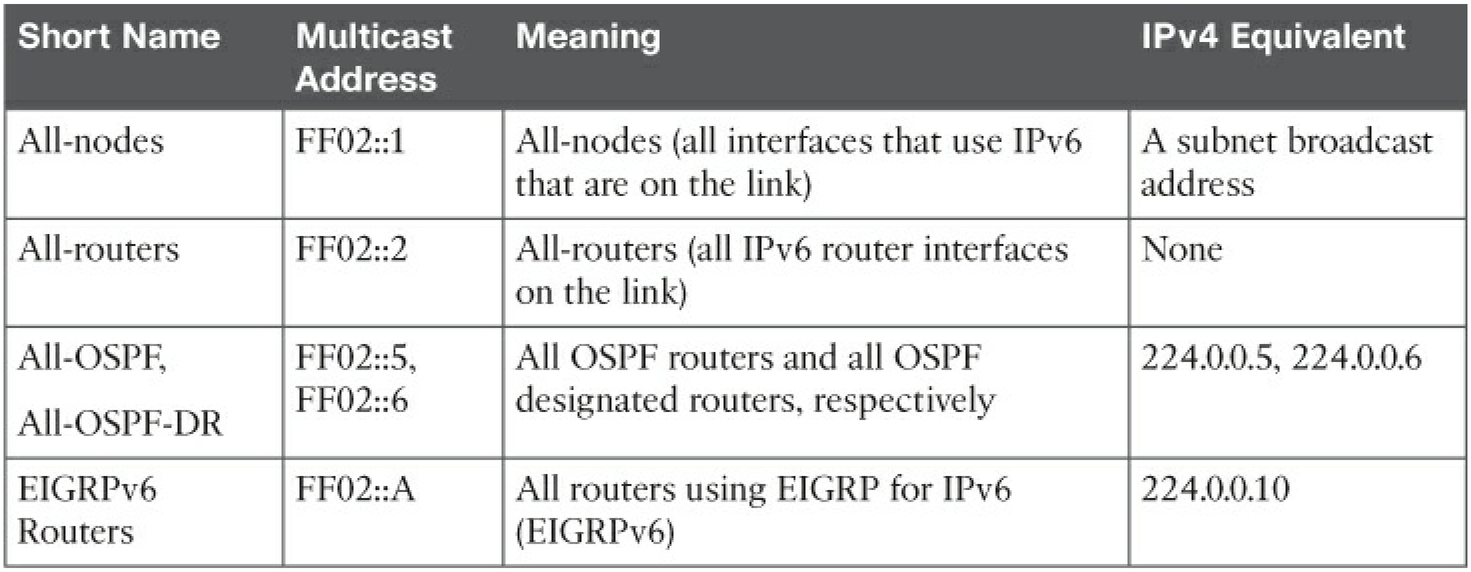
In some cases, multicast messages need to stay within one subnet, but in other cases, they need to be able to flow to many subnets. Some multicast addresses imply that a packet sent to that address should stay on the link; these addresses have a link-local scope. Multicast addresses that allow the packets to be routed to other subnets inside the enterprise have an organization-local scope.

For the purposes of this book, you will see a few link-local scope addresses on a regular basis. The Internet Assigned Numbers

Authority (IANA) reserves all IPv6 addresses that begin with FF, or more formally, prefix FF00::/8, for IPv6 multicasts. Within that range, IANA reserves all that begin with FF02 (formally, FF02::/16) for link-local scope multicast addresses.

Table 27-3 lists the most common local-scope IPv6 multicast addresses.

Table 27-3. Key IPv6 Local-Scope Multicast Addresses



Short Name	Multicast Address	Meaning	IPv4 Equivalent
All-nodes	FF02::1	All-nodes (all interfaces that use IPv6 that are on the link)	A subnet broadcast address
All-routers	FF02::2	All-routers (all IPv6 router interfaces on the link)	None
All-OSPF, All-OSPF-DR	FF02::5, FF02::6	All OSPF routers and all OSPF designated routers, respectively	224.0.0.5, 224.0.0.6
EIGRPv6 Routers	FF02::A	All routers using EIGRP for IPv6 (EIGRPv6)	224.0.0.10

Example 27-8 repeats the output of the **show ipv6 interface** command to show the multicast addresses used by Router R1 on its G0/0 interface. In this case, the highlighted lines show the all-nodes address (FF02::1), all-routers (FF02::2), and EIGRPv6 (FF02::A).

Example 27-8. Verifying Static IPv6 Addresses on Router R1

Click here to view code image

```
R1# show ipv6 interface GigabitEthernet 0/0
GigabitEthernet0/0 is up, line protocol is up
IPv6 is enabled, link-local address is FE80::1FF:FE01:101
No Virtual link-local address(es):
Description: LAN at Site 1
Global unicast address(es):
2001:DB8:1111:1::1, subnet is 2001:DB8:1111:1::/64
Joined group address(es):
FF02::1
FF02::2
FF02::A
FF02::1:FF00:1
FF02::1:FF01:101
! Lines omitted for brevity
```

Solicited-Node Multicast Addresses

Many of the multicast addresses used by protocols in the scope of the CCENT and CCNA exams are simply numbers reserved by an RFC. We just need to remember the numbers and notice them in **show** commands. However, one particular type of multicast address, called the solicited-node multicast address, varies from host to host, so its value is not preset. This last topic of the chapter briefly describes this type of multicast address.

Some IPv6 multicast addresses have clear and meaningful short names. Terms like “all-nodes” (for multicast address FF02::1) or “all-routers” (for multicast address FF02::2) pretty much define the meaning. Frankly, the term “solicited-node” does not make the idea behind this multicast address jump off the page.

Generally speaking, the solicited-node multicast address provides a destination address so that one packet can be sent inside one IPv6 subnet (link-local), to all hosts whose unicast addresses happen to have the same value in the last six hex digits. While true, that first sentence is relatively long. The following list breaks down the concepts that effectively define what the solicited-node multicast address is, for a particular host:

- A multicast address (not a unicast address)
- Link-local scope
- Based on the unicast IPv6 address of the host
- Specifically based on the only last six hex digits of the unicast address

- Each host must listen for packets sent to its solicited-node multicast address
- All hosts whose unicast IPv6 addresses have the same value in the last six hex digits use this same solicited node multicast address, and process the same packets

This last bullet item gets to the key function of these solicited node multicast addresses. Packets sent to a particular solicited-node multicast address might go to just one host. However, if more than one host in a subnet happens to have equal values in the last six hex digits of its unicast addresses, that same multicast packet is processed by both/all hosts. And some protocols want this kind of logic, of sending one multicast packet to all hosts who happen to have these similar unicast IPv6 addresses. As a result, the solicited-node multicast address was born.

> **Note**
>
> An alternate name, like "The link-local multicast address in common to all hosts with the same last six hex digits of their respective unicast addresses," would be a much more meaningful name instead of "solicited-node" multicast. However, as long as you know the meaning, just memorize the true name.

All IPv6 hosts must listen for messages sent to their solicited-node multicast address(es). So, for each interface, and for each unicast address on each interface, the device must determine its solicited node multicast address(es), and listen for packets sent to those addresses.

The logic to find a solicited-node multicast address, after you know the unicast address, is simple. Start with the predefined /104 prefix shown in Figure 27-9. In other words, all the solicited-node multicast addresses begin with the abbreviated FF02::1:FF. In the last 24 bits (6 hex digits), copy the unicast address into the solicited-node address.

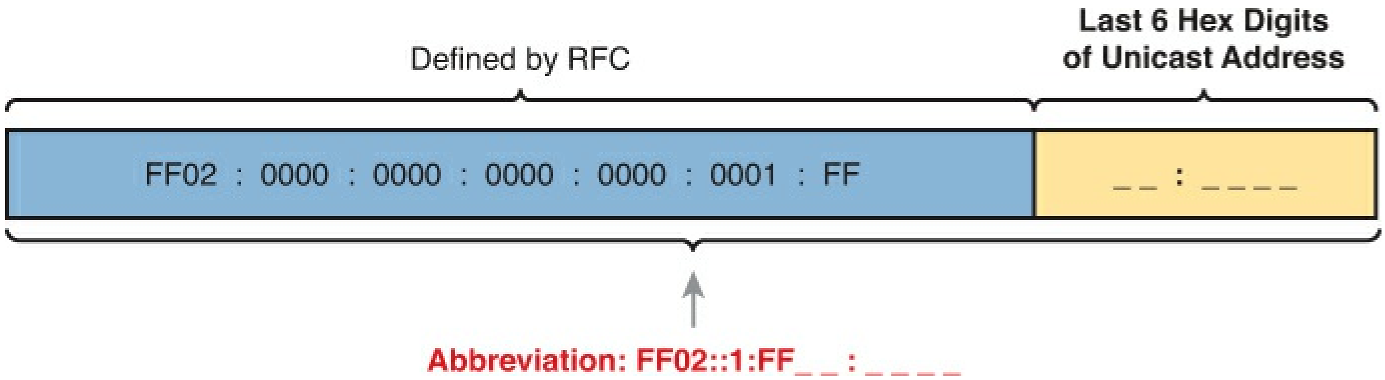

Defined by RFC
Last 6 Hex Digits of Unicast Address
FF02 : 0000 : 0000 : 0000 : 0000 : 0001 : FF
__ : ____
Abbreviation: FF02::1:FF__ : ____

Figure 27-9. Solicited-Node Multicast Address Format

To see samples of these addresses on a router, look back to the previous Example 27-8. The last two lines of command output show the solicited-node multicast addresses for Router R1's G0/0 interface: FF02::1:FF00:1 and FF02::1:FF01:101. Note that in this case, the reason R1's G0/0 has two such addresses is that one matches the router's global unicast address on that interface, while the other matches the link-local (unicast) address.

Miscellaneous IPv6 Addresses

Together, this chapter and the previous chapter have introduced most of the IPv6 addressing concepts included in this book. This short topic mentions a few remaining IPv6 addressing ideas and summarizes the topics for easy study.

First, all IPv6 hosts can use two additional special addresses:

- The unknown (unspecified) IPv6 address, ::, or all 0s
- The loopback IPv6 address, ::1, or 127 binary 0s with a single 1

The unknown address (::) can be used by a host when it's own IPv6 address is not yet known, or when the host wonders if its own IPv6 address might have problems. For example, hosts use the unknown address during the early stages of dynamically discovering their IPv6 address. When a host does not yet know what IPv6 address to use, it can use the :: address as its source IPv6 address.

The IPv6 loopback address gives each IPv6 host a way to test its own protocol stack. Just like the IPv4 127.0.0.1 loopback address, packets sent to ::1 do not leave the host, but are instead simply delivered down the stack to IPv6, and back up the stack to the application on the local host.

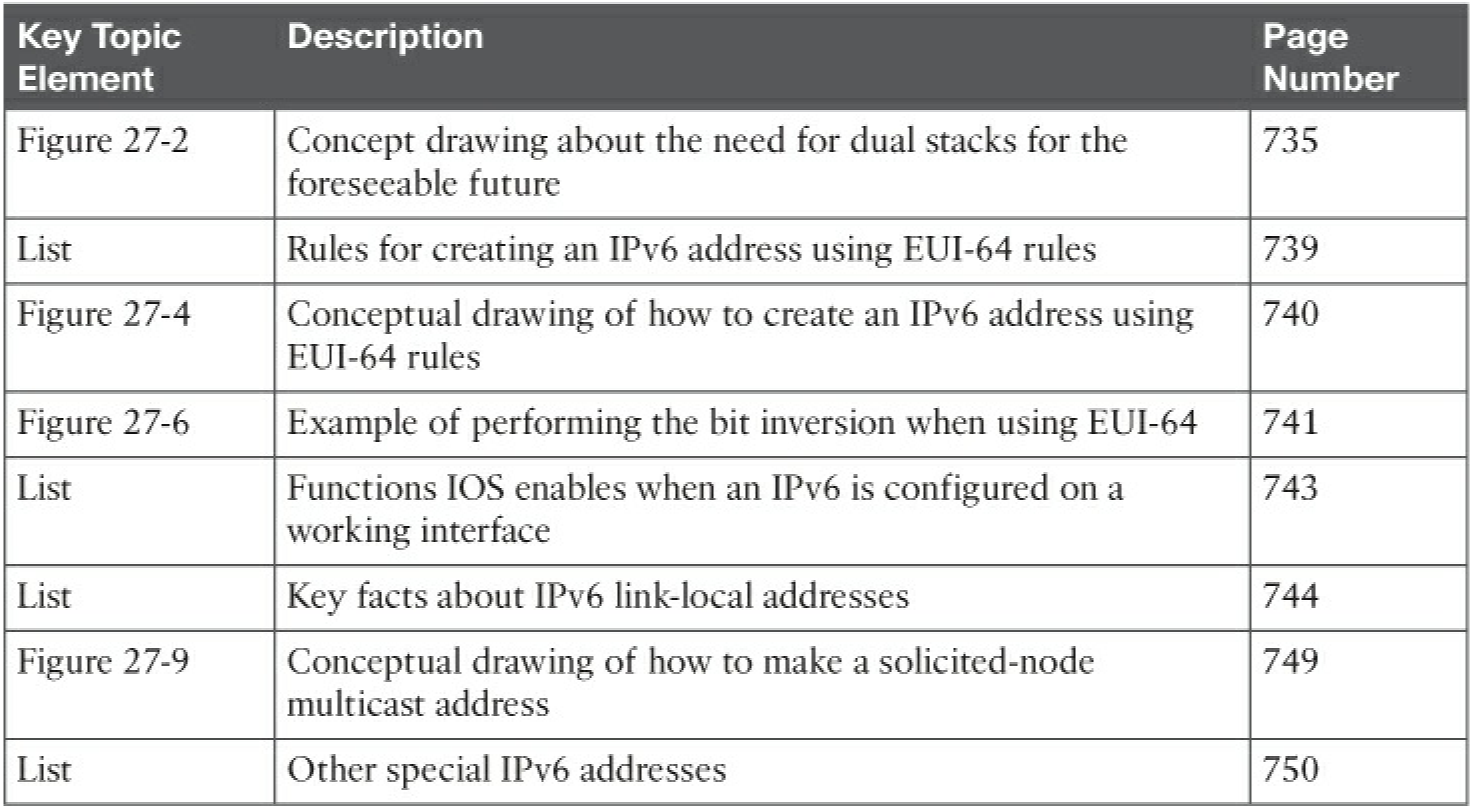
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 27-4 lists these key topics and where each is discussed.

Key Topic

Table 27-4. Key Topics for Chapter 27



Key Topic Element	Description	Page Number
Figure 27-2	Concept drawing about the need for dual stacks for the foreseeable future	735
List	Rules for creating an IPv6 address using EUI-64 rules	739
Figure 27-4	Conceptual drawing of how to create an IPv6 address using EUI-64 rules	740
Figure 27-6	Example of performing the bit inversion when using EUI-64	741
List	Functions IOS enables when an IPv6 is configured on a working interface	743
List	Key facts about IPv6 link-local addresses	744
Figure 27-9	Conceptual drawing of how to make a solicited-node multicast address	749
List	Other special IPv6 addresses	750

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists for you to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

- dual stacks
- EUI-64
- link-local address
- link-local scope
- solicited-node multicast address
- all-nodes multicast address

all-routers multicast address

Additional Practice with IPv6 Address Abbreviations

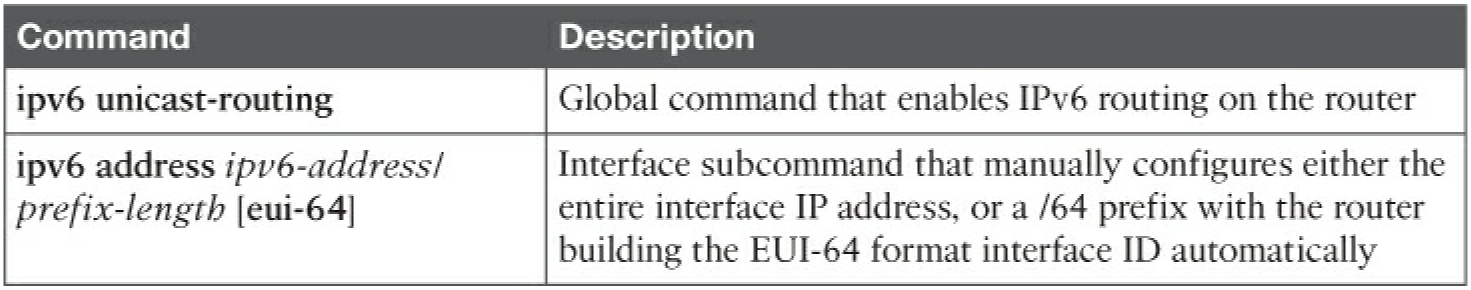
For additional practice with finding EUI-64 addresses and with solicited-node multicast addresses:

- DVD Appendix L, "Practice for Chapter 27: Implementing IPv6 Addressing on Routers," has some additional practice problems listed for both EUI-64 and solicited-node multicast addresses.
- Create your own problems using any real router or simulator. Get into the router CLI, into configuration mode, and configure the **mac-address** *address* and **ipv6 address** *prefix*/**64 eui-64** command. These commands (respectively) change the MAC address used on the interface and tell the router to create an IPv6 using EUI-64 rules. Then, before looking at the IPv6 address chosen by the router, do the calculations yourself. Finally, use the **show ipv6 interface** command to see the unicast address as well as the solicited-node multicast address.

Command Reference to Check Your Memory

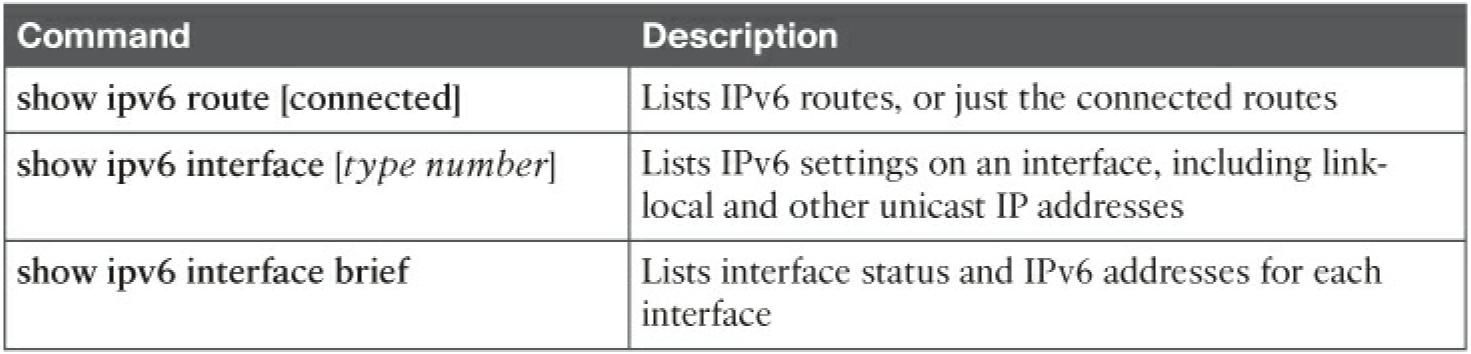
Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To check to see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table with a piece of paper, read the descriptions on the right side, and see whether you remember the command.

Table 27-5. Chapter 27 Configuration Command Reference



Command	Description
ipv6 unicast-routing	Global command that enables IPv6 routing on the router
ipv6 address *ipv6-address*/*prefix-length* [**eui-64**]	Interface subcommand that manually configures either the entire interface IP address, or a /64 prefix with the router building the EUI-64 format interface ID automatically

Table 27-6. Chapter 27 EXEC Command Reference



Command	Description
show ipv6 route [**connected**]	Lists IPv6 routes, or just the connected routes
show ipv6 interface [*type number*]	Lists IPv6 settings on an interface, including link-local and other unicast IP addresses
show ipv6 interface brief	Lists interface status and IPv6 addresses for each interface

Answers to Earlier Practice Problems

Table 27-2, earlier in this chapter, listed several practice problems in which you needed to calculate the IPv6 address based on EUI-64 rules. Table 27-7 lists the answers to those problems.

Table 27-7. Answers to IPv6 EUI-64 Address Creation Practice

Prefix	MAC Address	Unabbreviated IPv6 Address
2001:DB8:1:1::/64	0013.ABAB.1001	2001:DB8:1:1:0213:ABFF:FEAB:1001
2001:DB8:1:1::/64	AA13.ABAB.1001	2001:DB8:1:1:A813:ABFF:FEAB:1001
2001:DB8:1:1::/64	000C.BEEF.CAFE	2001:DB8:1:1:020C:BEFF:FEEF:CAFE
2001:DB8:1:1::/64	B80C.BEEF.CAFE	2001:DB8:1:1:BA0C:BEFF:FEEF:CAFE
2001:DB8:FE:FE::/64	0C0C.ABAC.CABA	2001:DB8:FE:FE:0E0C:ABFF:FEAC:CABA
2001:DB8:FE:FE::/64	0A0C.ABAC.CABA	2001:DB8:FE:FE:080C:ABFF:FEAC:CABA

Chapter 28. Implementing IPv6 Addressing on Hosts

This chapter covers the following exam topics:

LAN Switching Technologies

Verify network status and switch operation using basic utilities such as ping, telnet and ssh.

IP addressing (IPv4 / IPv6)

Describe the technological requirements for running IPv6 in conjunction with IPv4 such as dual stack

Describe IPv6 addresses

autoconfiguration

IP Routing Technologies

Verify router configuration and network connectivity

IP Services

Configure and verify DHCP (IOS Router)

configuring router interfaces to use DHCP

Troubleshooting

Troubleshoot and correct common problems associated with IP addressing and host configurations.

IPv6 hosts act like IPv4 hosts in many ways, using similar ideas, similar protocols, and even similar or identical commands for the same purpose. At the same time, IPv6 sometimes takes a much different approach than does IPv4, using a much different solution with a new protocol or command. For example:

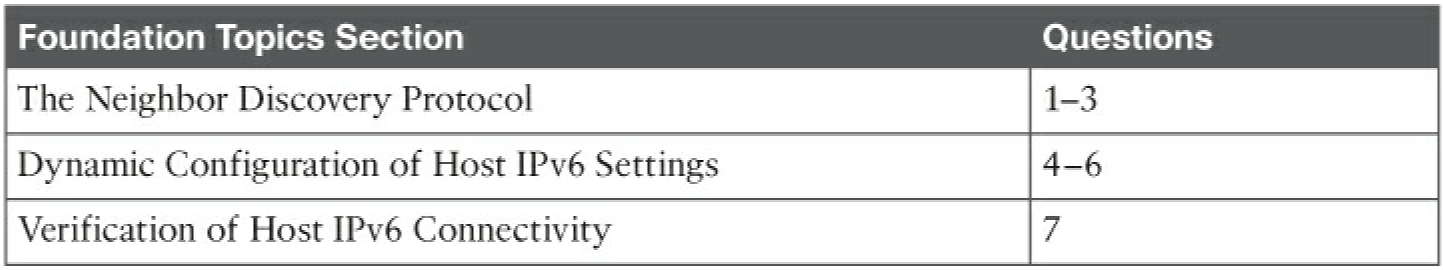
- Similar to IPv4, IPv6 hosts use a unicast address, prefix length (mask), default router, and DNS server.
- Similar to IPv4, IPv6 uses a protocol to dynamically learn the MAC address of other hosts in the same LAN-based subnet.
- Unlike IPv4, IPv6 hosts use the Neighbor Discovery Protocol (NDP) for many functions, including the functions done by IPv4's ARP.
- Similar to IPv4, IPv6 hosts can use DHCP to learn their four primary IPv6 settings.
- Unlike IPv4, IPv6 supports another dynamic address assignment process other than DHCP, called Stateless Address Autoconfiguration (SLAAC).

This chapter focuses on the four primary IPv6 settings on hosts: the address, prefix length, default router address, and DNS server address. However, to understand how hosts dynamically learn those addresses, this chapter begins its first major section devoted to NDP, which plays a key role in several IPv6 processes. The middle section of the chapter then focuses on how hosts dynamically learn their IPv6 settings, with both DHCP and SLAAC. The final major section of this chapter looks at the tools to verify a host's IPv6 settings—many of which use the same commands used for IPv4.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 28-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
The Neighbor Discovery Protocol	1–3
Dynamic Configuration of Host IPv6 Settings	4–6
Verification of Host IPv6 Connectivity	7

1. PC1, PC2, and Router R1 all connect to the same VLAN and IPv6 subnet. PC1 wants to send its first IPv6 packet to PC2. What protocol or message will PC1 use to discover the MAC address to which PC1 should send the Ethernet frame that encapsulates this IPv6 packet?

   a. ARP

   b. NDP NS

   c. NDP RS

   d. SLAAC

2. PC1 and Router R1 connect to the same VLAN and IPv6 subnet. The user of PC1 pings the IPv6 address of a host that sits at a remote site, so that the packets flow through R1, PC1's default router. PC1 did not statically configure its default router setting. Which of the following answers lists a protocol or message that PC1 could have used when trying to learn what IPv6 address to use as its default router?

   a. EUI-64
   b. NDP NS
   c. DAD
   d. NDP RS

3. Which of the following pieces of information does a router supply in an NDP Router Advertisement (RA) message? (Choose two answers.)
   a. Router IPv6 address
   b. Host name of the router
   c. IPv6 prefix(es) on the link
   d. IPv6 address of DHCP server
4. Host PC1 dynamically learns its IPv6 settings using stateful DHCPv6. Which one of PC1's settings is least likely to be learned from the stateful DHCPv6 server?
   a. Host address
   b. Prefix length
   c. Default router address
   d. DNS server address(es)
5. Host PC1 dynamically learns its IPv6 settings using Stateless Address Autoconfiguration (SLAAC). Which one of PC1's settings is most likely to be learned from the stateless DHCPv6 server?
   a. Host address
   b. Prefix length
   c. Default router address
   d. DNS server address(es)
6. Host PC1 dynamically learns its IPv6 settings using Stateless Address Autoconfiguration (SLAAC). Think about the host's unicast address as two parts: the prefix and the interface ID. Which of the answers list a way that SLAAC learns or builds the value of the interface ID portion of the host's address? (Choose two answers.)
   a. Learned from a DHCPv6 server
   b. Built by the host using EUI-64 rules
   c. Learned from a router using NDP RS/RA messages
   d. Built by the host using a random value
7. Three routers connect to the same VLAN and IPv6 subnet. All three routers have sent NDP RA messages, in reply to various IPv6 hosts' NDP RS messages, asking to learn about the available IPv6 routers in the subnet. A network engineer issues the **show ipv6 neighbors** command on R1. Which of the answers best describes the kind of NDP information held in this output?
   a. IPv6 neighbors (both routers and hosts) plus their MAC addresses, without noting which are routers
   b. IPv6 neighbors (both routers and hosts) plus their MAC addresses, and also noting which are routers
   c. IPv6 routers, with no information about nonrouters, with no MAC address info
   d. IPv6 routers, with no information about nonrouters, with MAC address info

Answers to the "Do I Know This Already?" quiz:

1 B **2** D **3** A and C **4** C **5** D **6** B and D **7** A

Foundation Topics

The Neighbor Discovery Protocol

IPv6 hosts need to know several important IPv6 settings that mirror the settings needed on IPv4 hosts: an address, the associated prefix length (mask equivalent), the default router address, and the DNS server address(es). Figure 28-1 shows those four concepts for PC1 on the left.

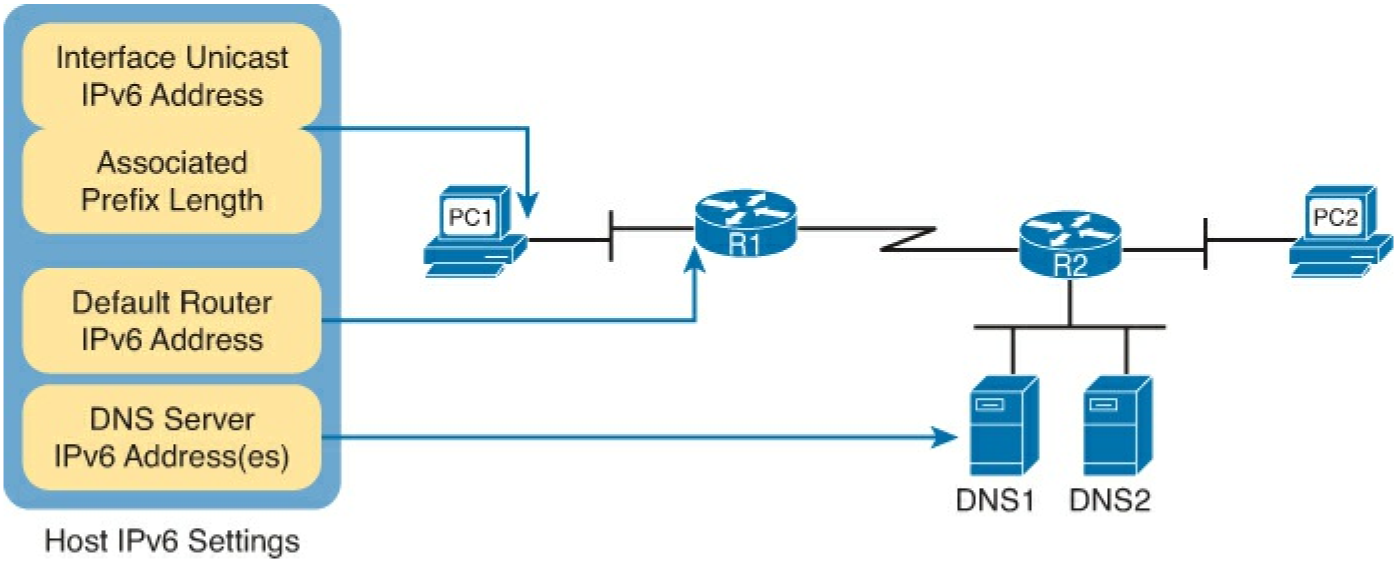

Interface Unicast IPv6 Address
Associated Prefix Length
Default Router IPv6 Address
DNS Server IPv6 Address(es)
Host IPv6 Settings
PC1
R1
R2
PC2
DNS1
DNS2

Figure 28-1. IPv6 Settings Needed on Hosts

Note that of the four settings, three are unicast IPv6 addresses. The PC's own IPv6 address is typically a global unicast or unique local unicast, as are the PC's references to the DNS servers. However, because the default router must be locally reachable, the default router setting typically refers to the router's link-local address.

Neighbor Discovery Protocol (NDP) defines several different functions related to IPv6 addressing, as follows:

Key Topic

- **SLAAC:** When using Stateless Address Autoconfiguration (SLAAC), the host uses NDP messages to learn the first part of its address, plus the prefix length.
- **Router Discovery:** Hosts learn the IPv6 addresses of the available IPv6 routers in the same subnet using NDP messages.
- **Duplicate Address Detection:** No matter how a host sets or learns its IPv6 address, the host waits to use the address until the host knows that no other host uses the same address. How does a host detect this problem? Using NDP messages, of course, through a process called Duplicate Address Detection (DAD).
- **Neighbor MAC Discovery:** After a host has passed the DAD process, and uses its IPv6 address, a LAN-based host will need to learn the MAC address of other hosts in the same subnet. NDP replaces IPv4's ARP, providing messages that replace the ARP Request and Reply messages.

The rest of this section steps through each of these four functions to varying degrees. Note that this section defers most of the discussion of the SLAAC process until later in the chapter, focusing more on the core NDP functions in this section.

Discovering Routers with NDP RS and RA

NDP defines a matched pair of messages that let a host dynamically discover all potential default routers that sit on the same data link. Basically, the process works with the host multicasting a message asking "routers, tell me about yourselves," and the routers reply. The messages are:

Key Topic

Router Solicitation (RS): Sent to the "all-IPv6-routers" local-scope multicast address of FF02::2, so that the message asks all routers, on the local link only, to identify themselves.

Router Advertisement (RA): This message, sent by the router, lists many facts, including the link-local IPv6 address of the router. When unsolicited, it is sent to the all-IPv6-hosts local-scope multicast address of FF02::1. When sent in response to an RS message, it flows back to either the unicast address of the host that sent the NS, or to the all-IPv6-hosts address FF02::1.

For example, Figure 28-2 shows how host PC1 can learn R1's link-local address. The process is indeed simple, with PC1 first asking and R1 replying.

Key Topic

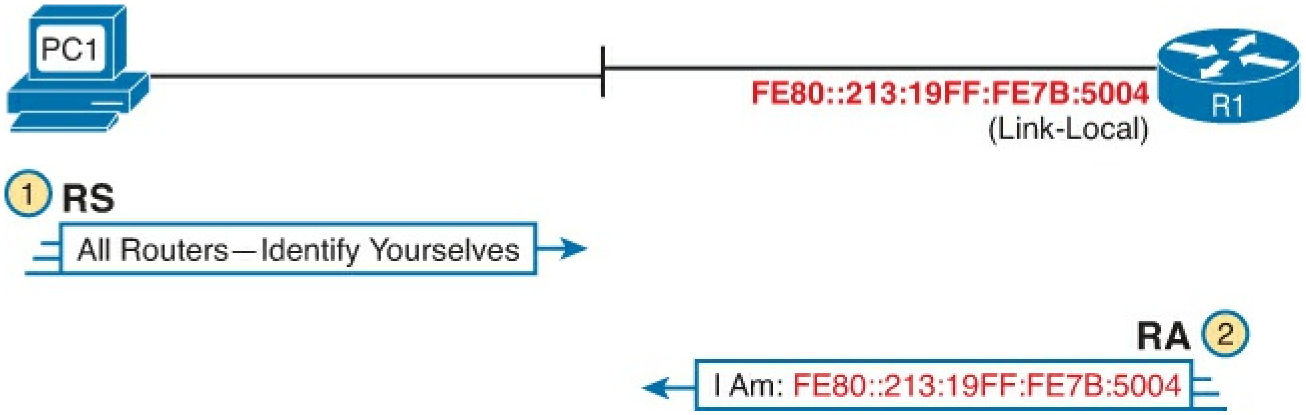

PC1
FE80::213:19FF:FE7B:5004
(Link-Local)
R1
① RS
All Routers—Identify Yourselves
RA ②
I Am: FE80::213:19FF:FE7B:5004

Figure 28-2. Example NDP RS/RA Process to Find the Default Routers

> **Note**
>
> IPv6 allows multiple prefixes and multiple default routers to be listed in the RA message; the figure just shows one of each for simplicity's sake.

IPv6 does not use broadcasts, but it does use multicasts. In this case, the RS message flows to the all-routers multicast address (FF02::2) so that all routers will receive the message. It has the same good effect as a broadcast with IPv4, without the negatives of a broadcast. In this case, only IPv6 routers will spend any CPU cycles processing the RS message. The RA message can flow either to the unicast IPv6 address of PC1 or to the all nodes FF02::1 address.

Note that while Figure 28-2 shows how a host can ask to learn about any routers, routers also periodically send unsolicited RA messages, even without an incoming RS. When routers send these periodic RA messages, they basically advertise details about IPv6 on the link. In this case, the RA messages flow to the FF02::1 all-nodes IPv6 multicast address.

Discovering Addressing Info for SLAAC with NDP RS and RA

While the NDP RS and RA messages identify IPv6 routers, these messages also supply other pieces of information as well. If you think about the messages more generally, RS gives a host a means to request information more general, like this: "IPv6 routers, tell me information that you know!" The RA message gives IPv6 routers a means to distribute the information: "Here is the information that I know!" Figure 28-2 just happens to show one fact learned through the RS and RA messages, namely the IPv6 address of the IPv6 router.

Another fact that routers know is the prefix and prefix length used on the local link. Routers typically have an **ipv6 address** command on each interface; that command lists the prefix length and enough information for the router to calculate the associated IPv6 prefix. A host can learn these details using the RS and RA message exchange, as shown in Figure 28-3.

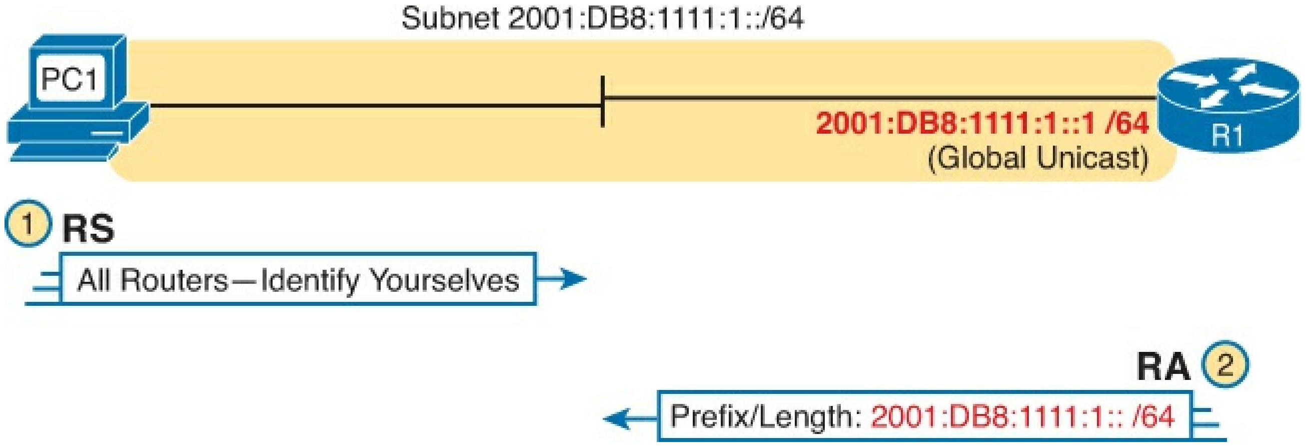

Subnet 2001:DB8:1111:1::/64
PC1
2001:DB8:1111:1::1 /64
(Global Unicast)
R1
① RS
All Routers—Identify Yourselves
RA ②
Prefix/Length: 2001:DB8:1111:1:: /64

Figure 28-3. Using NDP RS/RA to Discover the Prefix/Length on the LAN

As it turns out, the SLAAC process, used by hosts to dynamically learn an IPv6 address, uses the prefix/prefix length information learned from the router using RS and RA messages. The later section "Using Stateless Address Autoconfiguration" discusses the entire process.

Discovering Neighbor Link Addresses with NDP NS and NA

NDP defines a second pair of matched solicitation and advertisement messages: the neighbor solicitation (NS) and neighbor advertisement (NA) messages. Basically, the NS acts like an IPv4 ARP request, asking the host with a particular unicast IPv6 address to send back a reply. The NA message acts like an IPv4 ARP Reply, listing that host's MAC address.

The process of sending the NS and NA messages follows the same general process as RS and RA: The NS message asks for information and the NA supplies the information. The most obvious difference is that while RS/RA focuses on information held by routers, NS/NA focuses on information that could be held by any IPv6 host. Also, note that the NS messages goes to the solicited-node multicast address associated with the target; see Chapter 27's topic "Solicited-Node Multicast Addresses" for a reminder of this type of address.

Key Topic

- **Neighbor Solicitation (NS):** Asks a host with a particular IPv6 address (the target address) to send back an NA with its MAC address listed. The NS message is sent to the solicited-node multicast address associated with the target address, so that the message is processed only by hosts whose last six hex digits match the address which is being queried.
- **Neighbor Advertisement (NA):** This message lists the sender's address as the target address, along with the matching MAC address. It is sent back to the unicast address of the host that sent the original NS message. In some cases, a host sends an unsolicited NA, in which case the message is sent to the all-IPv6-hosts local-scope multicast address FF02::1.

> **Note**
>
> With NDP, the word "neighbor" refers to the fact that the devices will be on the same data link, for example, the same VLAN.

Figure 28-4 shows an example of how a host (PC1) uses an NS message to learn the MAC address used by another host. The NDP NS and NA messages replace the IPv4 ARP protocol in that it lets hosts discover the link-layer address of other IPv6 hosts on the same data link. (IPv6 refers to hosts on the same data link as simply *on-link*.) The NS message lists a target IPv6 unicast address, with the implied question: "What is your link address?" The NA message, in this example sent back to the original host that asked the question, lists that link address. Figure 28-4 shows an example.

Key Topic

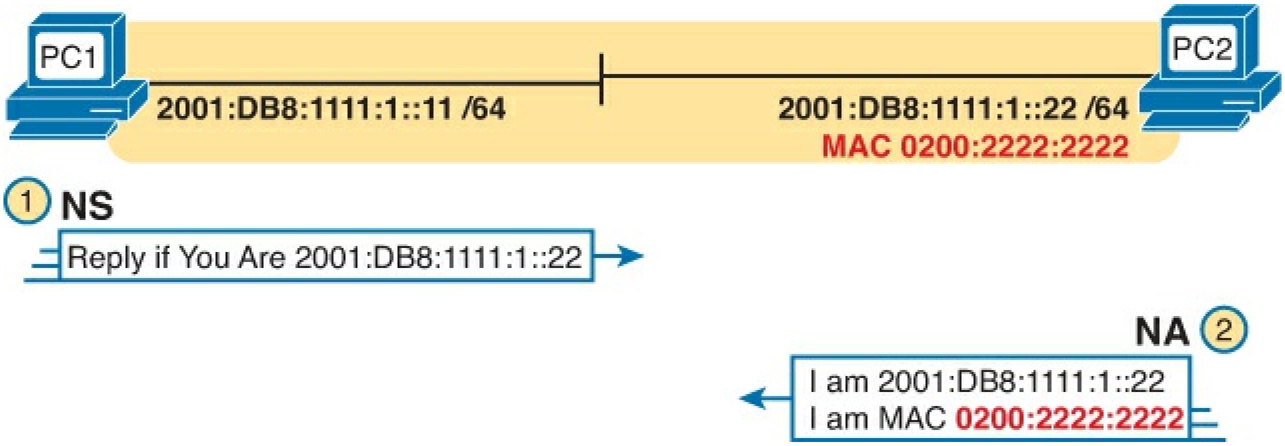


Figure 28-4. Example NDP NS/NA Process to Find the Link Address of On-Link Neighbors

At Step 1 of this particular example, PC1 sends the solicitation to find PC2's MAC address. PC1 first looks in its NDP neighbor table, the equivalent of the IPv4 ARP cache, and does not find the MAC address for IPv6 address 2001:DB8:1111:1::22. So, at Step 1, PC1 sends the NDP NS message to the matching solicited-node multicast address for 2001:DB8:1111:1::22, or FF02::1:FF00:22. Only IPv6 hosts whose address ends with 00:0022 will listen for this solicited-node multicast address. As a result, only a small subset of hosts on this link will process the received NDP NS message.

At Step 2, PC2 reacts to the received NS message. PC2 sends back an NA message in reply, listing PC2's MAC address. PC1 records PC2's MAC address in PC1's NDP neighbor table.

> **Note**
>
> To view a host's NDP neighbor table, use these commands: (Windows) **netsh interface ipv6 show neighbors**; (Linux) **ip -6 neighbor show**; (Mac OS) **ndp -an**.

Discovering Duplicate Addresses Using NDP NS and NA

The NDP NS/NA messages also require hosts to do an important check to avoid using duplicate IPv6 addresses. IPv6 uses the Duplicate Address Detection (DAD) process before using a unicast address to make sure that no other node on that link is already using the address. If another host already uses that address, the first host simply does not use the address until the problem is resolved.

The term DAD refers to the function, but the function uses NDP NS and NA messages. Basically, a host sends an NS message, but it lists the address the host wants to use as the target address. If no duplicate exists, no other host should reply with an NA. However, if another host already uses that address, that host will reply with an NA, identifying a duplicate use of the address. Figure 28-5 shows an example in which a duplicate is detected.

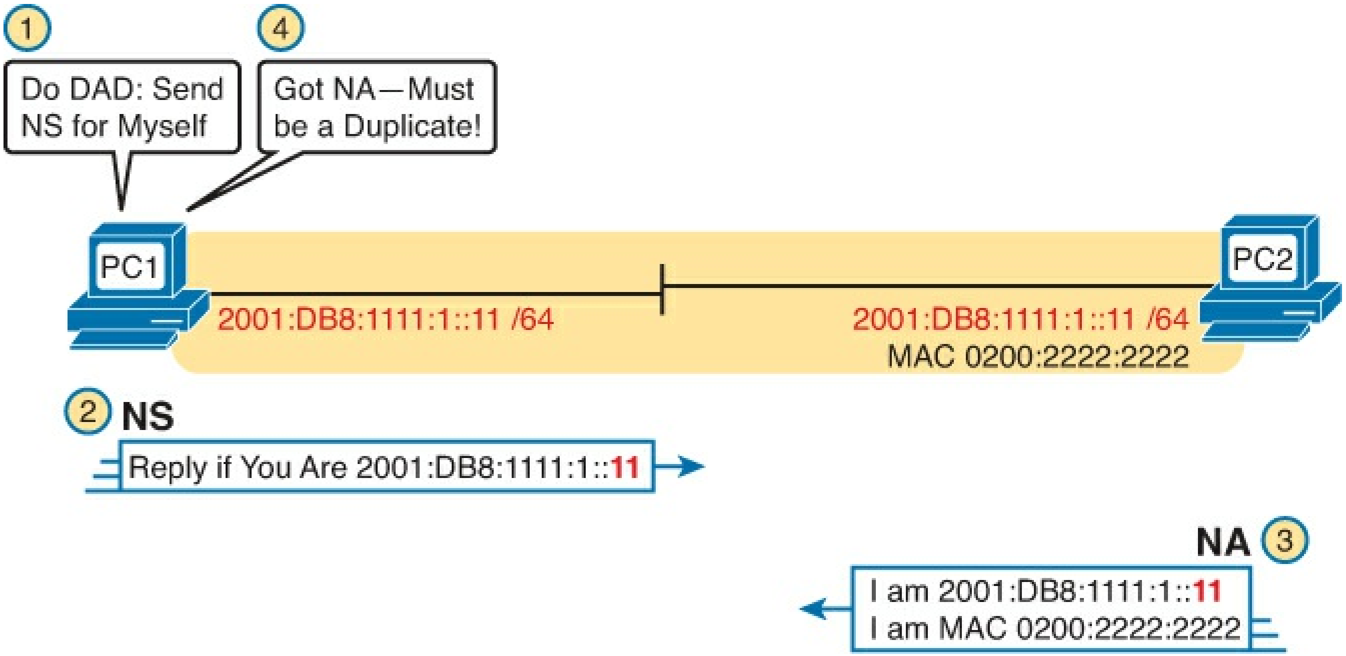

①
Do DAD: Send NS for Myself
④
Got NA—Must be a Duplicate!
PC1
PC2
2001:DB8:1111:1::11 /64
2001:DB8:1111:1::11 /64
MAC 0200:2222:2222
② NS
Reply if You Are 2001:DB8:1111:1::11
NA ③
I am 2001:DB8:1111:1::11
I am MAC 0200:2222:2222

Figure 28-5. Example NDP NS/NA Process to Find the Link Address of On-Link Neighbors

Figure 28-5 shows an example in which both PC1 and PC2 attempt to use the same IPv6 address. PC2 is already using the address, and PC1 uses DAD before using the address. The figure shows the following steps:

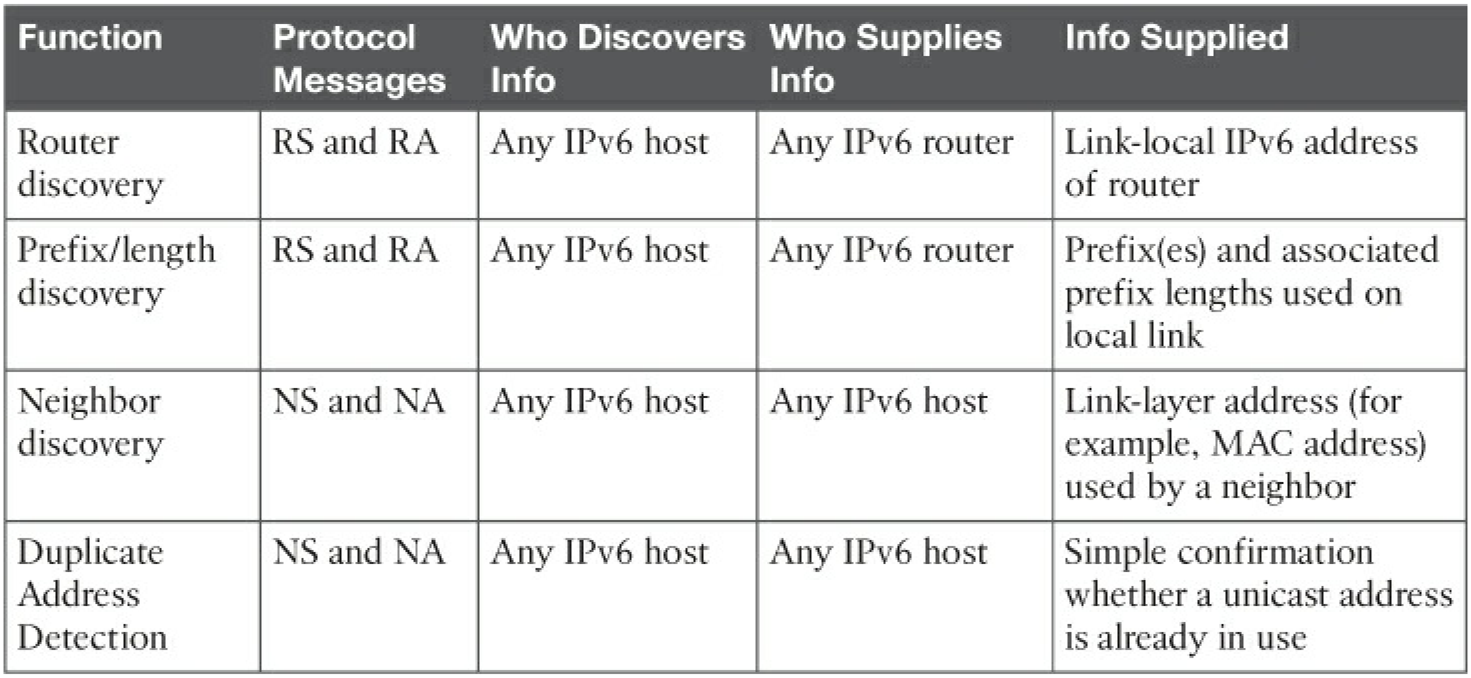
1. PC1, before using address 2001:DB8:1111:1::11, must use DAD.
2. PC1 sends an NS message, listing the address PC1 now wants to use (2001:DB8:1111:1::11) as the target.
3. PC2 receives the NS, sees what PC2 already uses as its own address, and sends back an NA.
4. PC1, on receiving the NA message for its own IPv6 address, realizes a duplicate address exists.

Hosts do the DAD check for each of their unicast addresses, link-local addresses included, both when the address is first used and each time the host's interface comes up.

NDP Summary

This chapter explains some of the more important functions performed by NDP. NDP does more than what is listed in this chapter, and the protocol allows for addition of other functions, so NDP might continue to grow. For now, use Table 28-2 as a study reference for the four NDP features discussed here.

Table 28-2. NDP Function Summary



Function	Protocol Messages	Who Discovers Info	Who Supplies Info	Info Supplied
Router discovery	RS and RA	Any IPv6 host	Any IPv6 router	Link-local IPv6 address of router
Prefix/length discovery	RS and RA	Any IPv6 host	Any IPv6 router	Prefix(es) and associated prefix lengths used on local link
Neighbor discovery	NS and NA	Any IPv6 host	Any IPv6 host	Link-layer address (for example, MAC address) used by a neighbor
Duplicate Address Detection	NS and NA	Any IPv6 host	Any IPv6 host	Simple confirmation whether a unicast address is already in use

Dynamic Configuration of Host IPv6 Settings

By the time IPv6 was created back in the early to mid 1990s, the world had a decade or two of experience with IPv4. That experience with IPv4 had already shown the need for hosts to dynamically learn their IPv4 settings, including the host's IPv4 address. By the time IPv6 was being created, DHCP for IPv4 had already become the preferred IPv4 solution to allow hosts to dynamically learn their IPv4 address and other settings.

DHCP worked well for IPv4, so creating a version of DHCP for IPv6 (DHCPv6) made perfect sense. However, while DHCP has many advantages, one possible disadvantage is that DHCP requires a server which keeps information about each host (client) and their address. The designers of IPv6 wanted an alternative dynamic address assignment tool, one that did not require a server. The answer? SLAAC.

This second major section of the chapter first looks at DHCPv6, followed by SLAAC.

Dynamic Configuration Using Stateful DHCP and NDP

DHCP for IPv6 (DHCPv6) gives an IPv6 host a way to learn host IPv6 configuration settings, using the same general concepts as DHCP for IPv4. The host exchanges messages with a DHCP server, and the server supplies the host with configuration information, including a lease of an IPv6 address, along with prefix length and DNS server address information.

> **Note**
>
> The DHCP version is not actually version 6; the name just ends in "v6" in reference to the support for IPv6.

More specifically, stateful DHCPv6 works like the more familiar DHCP for IPv4 in many other general ways, as follows:

Key Topic

- DHCP clients on a LAN send messages that flow only on the local LAN, hoping to find a DHCP server.
- If the DHCP server sits on the same LAN as the client, the client and server can exchange DHCP messages directly, without needing help from a router.
- If the DHCP server sits on another link as compared to the client, the client and server rely on a router to forward the DHCP messages.
- The router that forwards messages from one link, to a server in a remote subnet, must be configured as a DHCP Relay Agent, with knowledge of the DHCP server's IPv6 address.
- Servers have configuration that lists pools of addresses for each subnet from which the server allocates addresses.
- Servers offer a lease of an IP address to a client, from the pool of addresses for the client's subnet; the lease lasts a set time period (usually days or weeks).
- The server tracks state information, specifically a client identifier (often based on the MAC address), along with the address that is currently leased to that client.

DHCPv6 has two major branches of how it can be used: stateful DHCPv6 and stateless DHCPv6. Stateful DHCPv6 works more like the DHCPv4 model, especially related to that last item in the list. A stateful DHCPv6 server tracks information about which client has a lease for what IPv6 address; the fact that the server knows information about a specific client is called state information, making the DHCP server a stateful DHCP server.

Stateless DHCP servers do not track any per-client information. The upcoming section "Using Stateless Address Autoconfiguration" discusses how stateless DHCPv6 servers have an important role when a company decides to use SLAAC.

Differences Between DHCPv6 and DHCPv4

While stateful DHCPv6 has many similarities to DHCPv4, many particulars differ as well. Figure 28-6 shows one key difference: Stateful DHCPv6 does not supply default router information to the client. Instead, the client host uses the built-in NDP protocol to learn the routers' IPv6 addresses directly from the local routers.

Key Topic

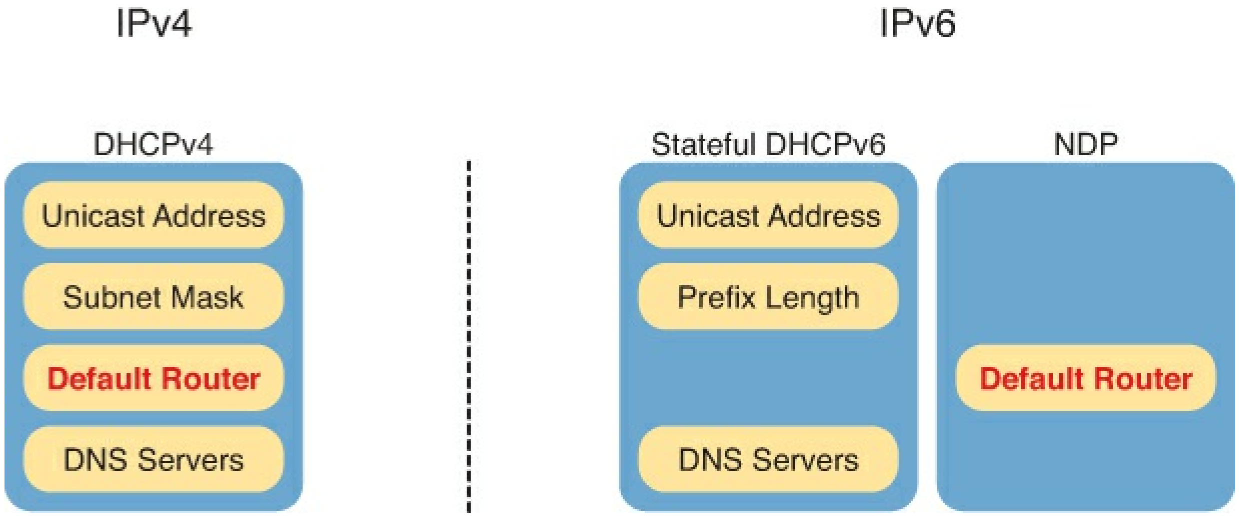


Figure 28-6. Sources of Specific IPv6 Settings When Using Stateful DHCP

DHCPv6 also updates the protocol messages to use IPv6 packets instead of IPv4 packets, with new messages and fields as well. For example, Figure 28-7 shows the names of the DHCPv6 messages, which replace the DHCPv4 Discover, Offer, Request, and Acknowledgment (DORA) messages. Instead, DHCPv6 uses the Solicit, Advertise, Request, and Reply messages.

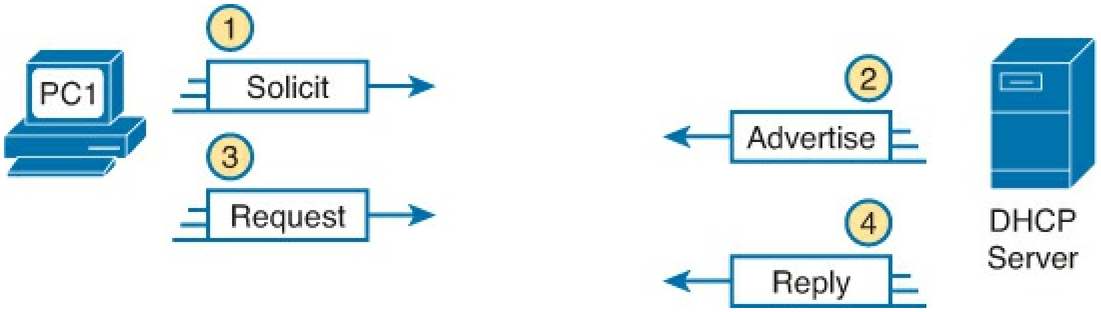


Figure 28-7. Four Stateful DHCPv6 Messages Between Client and Server

The four DHCPv6 messages work in two matched pairs with the same general flow as the similar DHCPv4 messages. The Solicit and Advertise messages complete the process of the client searching for the IPv6 address of a DHCPv6 server (the Solicit message), and the server advertising an address (and other configuration settings) for the client to possibly use (the Advertise message). The Request and Reply messages let the client ask to lease the address, with the server confirming the lease in the Reply message.

DHCPv6 Relay Agents

For enterprises that choose to use stateful DHCPv6, oftentimes the DHCP server sits at a central site, far away from many of the clients that use the DHCPv6 server. In those cases, the local router at each site must act as a DHCP relay agent.

The concepts of DHCPv6 relay work like DHCPv4 relay, as discussed in Chapter 18's section "Supporting DHCP for Remote Subnets with DHCP Relay." The client sends a message that only flows inside the local LAN. The router then changes the source and destination IP address, forwarding the packet to the DHCP server. When the server sends a reply, it actually flows to an address on the router (the relay agent), which changes the addresses in that packet as well.

The differences for IPv6 become more obvious when you look at some of the IPv6 addresses used in DHCPv6 messages, like the Solicit message used to lead off a DHCPv6 flow. As shown in Figure 28-8, the client uses the following addresses in the solicit message:

Source of link-local: The client uses its own link-local address as the source address of the packet.

Destination address of “all-DHCP-agents” FF02::1:2: This link-local scope multicast address is used to send packets to two types of devices: DHCP servers and routers acting as DHCP relay agents.

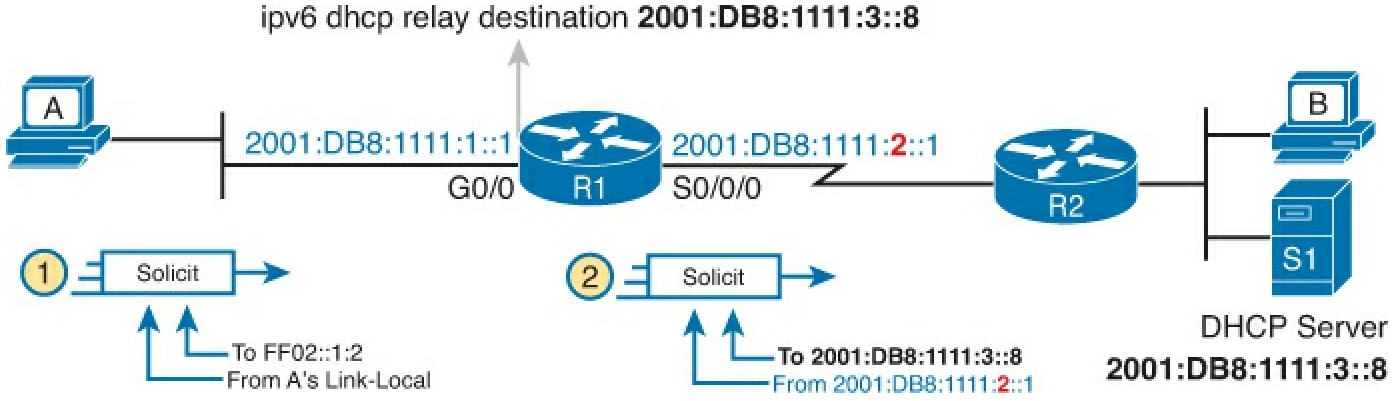


Figure 28-8. DHCPv6 Relay Agent and DHCP IPv6 Addresses

With a link-local scope multicast destination address, the Solicit message sent by a host would only flow on the local LAN. Figure 28-8 shows some of the particulars of how R1, acting as a DHCPv6 relay agent, assists DHCPv6 clients like host A to deliver DHCPv6 packets to the DHCPv6 server.

Focus first on Step 1, in which host A, the DHCPv6 client, builds and sends its DHCPv6 Solicit message. The message flows from host A’s link-local address, and to the all-DHCP-agents multicast address FF02::1:2. With a link-local scope multicast destination address, the Solicit message sent by a host would only flow on the local LAN.

Step 2 shows the results of R1’s work as the DHCPv6 relay agent. R1 listens for incoming DHCPv6 messages sent to FF02::1:2, and processes the message sent by host A. R1 changes the destination IPv6 address of the packet to match the DHCPv6 server on the right. R1 also changes the source IPv6 address to be one of R1’s IPv6 addresses. With DHCPv6, by default R1 uses the address of its outgoing interface (S0/0/0) as the source IPv6 address, which is slightly different from the DHCPv4 relay agent. R1 then forwards the Solicit message to the server.

The return DHCPv6 messages from the server to the client (not shown in the figure) flow first to the relay agent router’s IPv6 address—in other words, to 2001:DB8:1111:2::1 in this case. The relay agent then converts the destination address of those messages as well, and forwards the DHCPv6 messages to the client’s link-local address.

Example 28-1 shows the DHCPv6 relay agent configuration for R1 in Figure 28-8. The top of the example shows the **ipv6 dhcp relay** interface subcommand, with reference to the IPv6 address of the DHCPv6 server. The bottom of the figure shows the output of the **show ipv6 interface** command, which confirms that R1 is now listening for multicasts sent to the all-DHCP-agents multicast address FF02::1:2.

Example 28-1. Configuring Router R1 to Support Remote DHCPv6 Server

Click here to view code image

```
interface GigabitEthernet0/0
ipv6 dhcp relay destination 2001:DB8:1111:3::8

R1# show ipv6 interface g0/0
GigabitEthernet0/0 is up, line protocol is up
IPv6 is enabled, link-local address is FE80::FF:FE00:1
No Virtual link-local address(es):
Description: to SW1 port F0/1
Global unicast address(es):
2001:DB8:1111:1::1, subnet is 2001:DB8:1111:1::/64 [EUI]
Joined group address(es):
FF02::1
FF02::2
FF02::A
FF02::1:2
FF02::1:FF00:1
! Lines omitted for brevity
```

Using Stateless Address Autoconfiguration

The stateful nature of DHCPv4, as well as its newer cousin stateful DHCPv6, causes some challenges. Someone has to configure, administer, and manage the DHCP server(s). The configuration includes ranges of IP addresses for every subnet. Then, when a host (client) leases the address, the server notes which client is using which address. All these functions work, and work well, but the reliance on a stateful DHCP server requires some thought and attention from the IT staff.

IPv6’s Stateless Address Autoconfiguration (SLAAC) provides an alternative method for dynamic IPv6 address assignment—

without needing a stateful server. In other words, SLAAC does not require a server to assign or lease the IPv6 address, does not require the IT staff to preconfigure data per subnet, and does not require the server to track which device uses which IPv6 address.

The term SLAAC refers to both a specific part of how a host learns one IPv6 setting—its IPv6 address—plus the overall process of learning all four key host IPv6 settings (address, prefix length, default router, and DNS server addresses). This next topic begins by looking at the tasks done by SLAAC related to the IPv6 address. Then, the text looks at the overall process that uses SLAAC to find all four host settings—a process that uses NDP as well as stateless DHCP.

Building an IPv6 Address Using SLAAC

When using SLAAC, a host does not lease its IPv6 address, or even learn its IPv6 address. Instead, the host learns part of the address—the prefix—and then makes up the rest of its own IPv6 address. Specifically, a host using SLAAC to choose its own IPv6 address uses the following steps:

Key Topic

1. Learn the IPv6 prefix used on the link, from any router, using NDP RS/RA messages
2. Choose its own IPv6 address by making up the interface ID value to follow the just-learned IPv6 prefix
3. Before using the address, first use DAD to make sure that no other host is already using the same address

Figure 28-9 summarizes the first two steps, while noting the two most common ways a host completes the address. Hosts can use EUI-64 rules, as discussed back in Chapter 27's section "Generating a Unique Interface ID Using EUI-64." Alternately, the host can use a process to choose a random number.

Key Topic

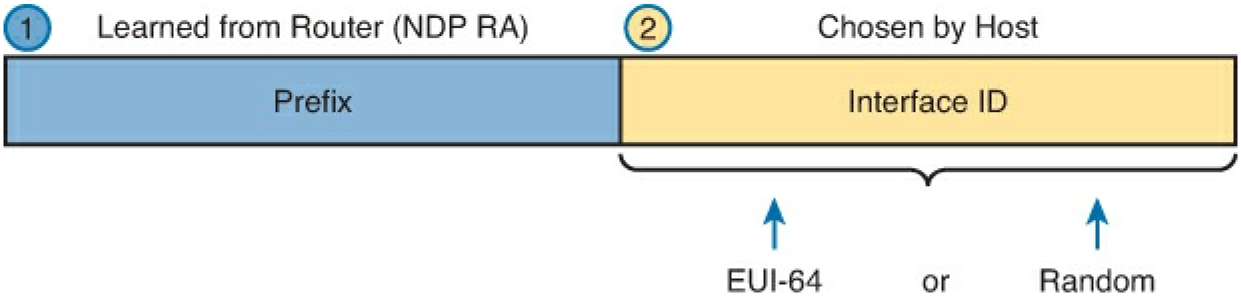


Figure 28-9. Host IPv6 Address Formation Using SLAAC

> **Note**
>
> Microsoft OSs generally use the option to randomly pick the interface ID, with clients picking different values over time, as a security measure.

Combining SLAAC with NDP and Stateless DHCP

When using SLAAC, a host actually makes use of three different tools to find its four IPv6 settings, as noted in Figure 28-10. SLAAC itself focuses on the IPv6 address only. The host then uses NDP messages to learn both the prefix length, as well as the IPv6 addresses of the available routers on the link. Finally, the host makes use of stateless DHCP to learn the IPv6 addresses of any DNS servers.

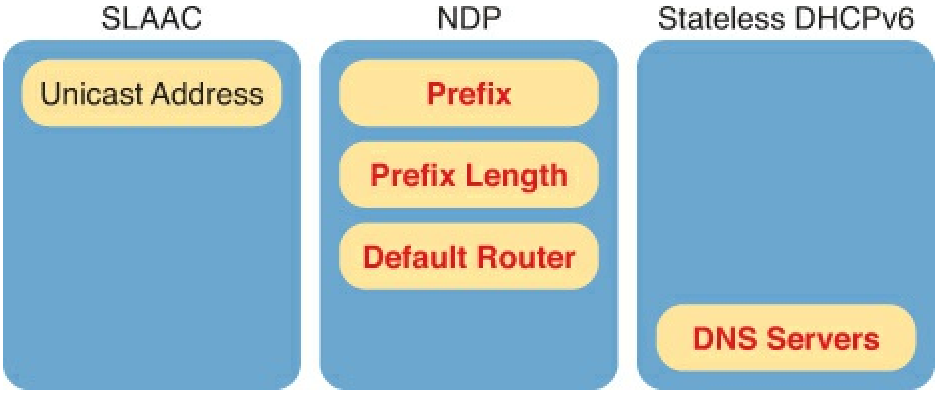


Figure 28-10. Sources of Specific IPv6 Settings When Using SLAAC

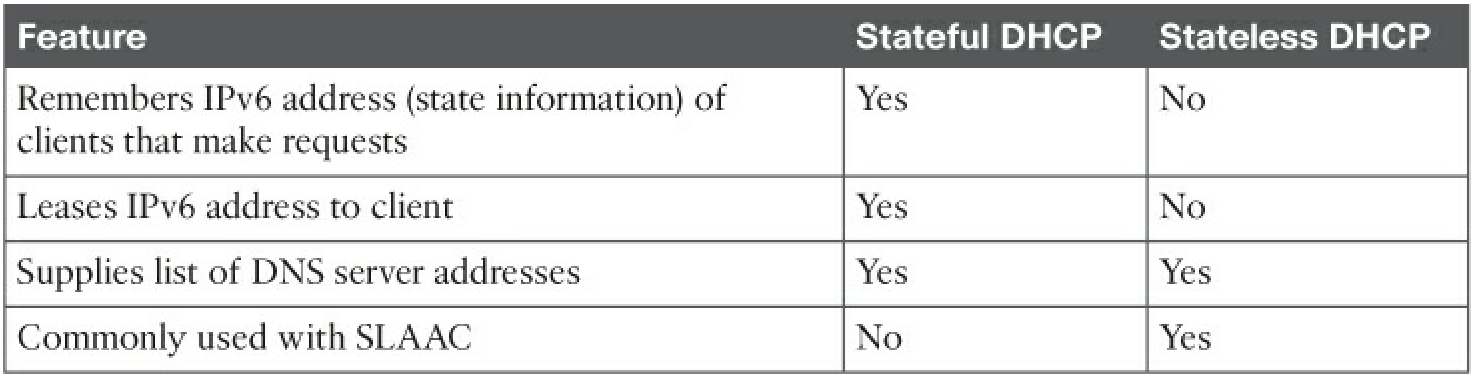
Stateless DHCP solves the last piece of this puzzle when also using SLAAC. The host needs to know the DNS servers' IPv6 addresses. The solution? Use DHCPv6. However, the host, acting as the DHCPv6 client, asks the server for only the DNS server addresses, and not for a lease of an IPv6 address.

So, why does the world need to call this service *stateless DHCPv6*? The DHCP server with stateless DHCPv6 has far less work to do, and the network engineer has far less administrative work to do. With stateless DHCPv6, the DHCPv6 server:

- Needs simple configuration only, specifically a small number of addresses for the DNS servers, but nothing else
- Needs no per-subnet configuration: no subnet list, no per-subnet address pools, no list of excluded addresses per subnet, and no per-subnet prefix lengths
- Has no need to track state information about DHCP leases—that is, which devices lease which IPv6 address—because the server does not lease addresses to any clients

Table 28-3 summarizes the key comparison points between stateless DHCP and stateful DHCP.

Table 28-3. Comparison of Stateless and Stateful DHCPv6 Services



Feature	Stateful DHCP	Stateless DHCP
Remembers IPv6 address (state information) of clients that make requests	Yes	No
Leases IPv6 address to client	Yes	No
Supplies list of DNS server addresses	Yes	Yes
Commonly used with SLAAC	No	Yes

Verification of Host IPv6 Connectivity

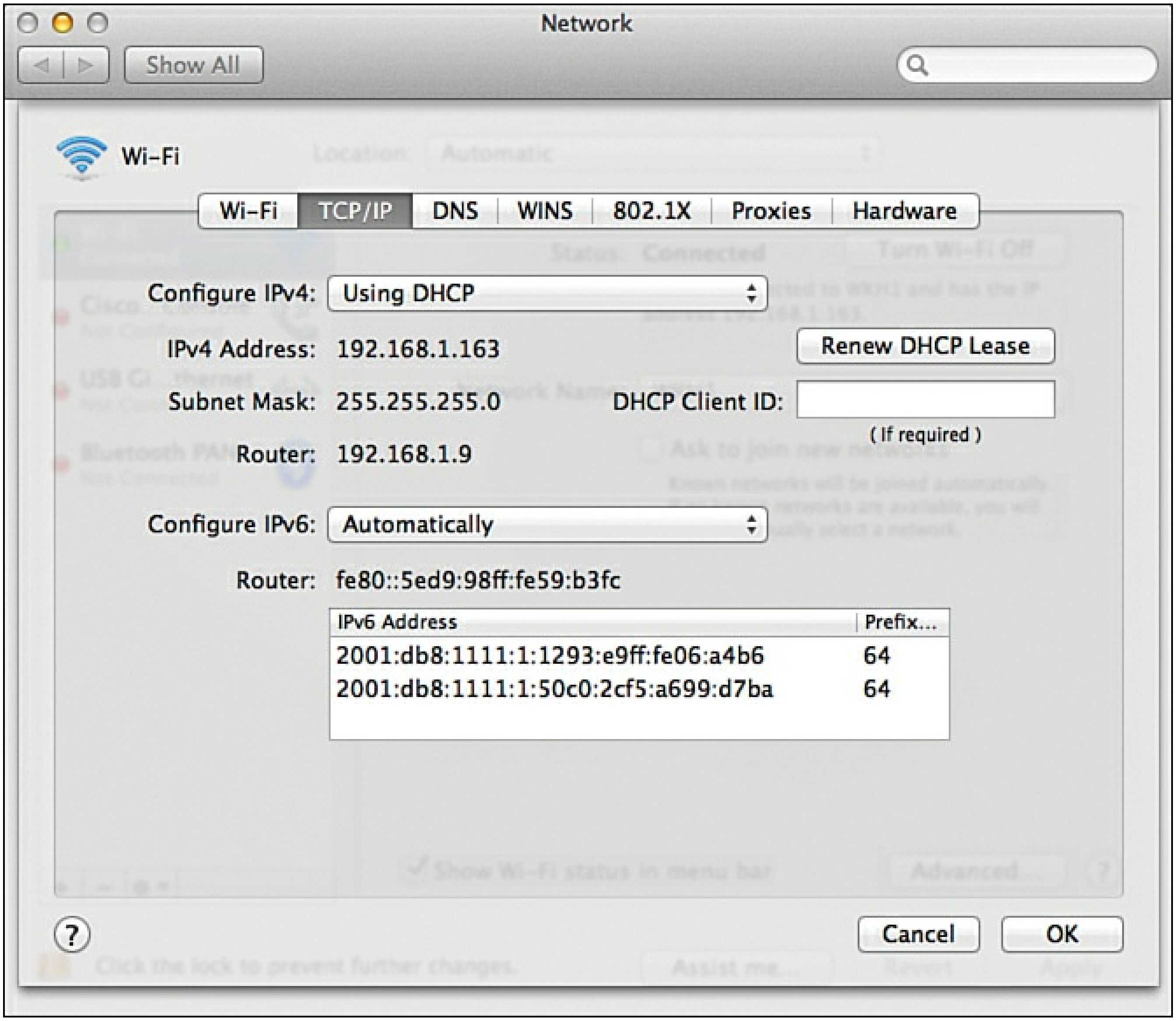
This third and final major section of the chapter examines a few commands to verify the settings on hosts. Specifically, this section examines the host's IPv6 settings, and then looks at the usual commands to test whether a host can send packets: **ping** and **traceroute**.

Note that this section lists some commands on different host OSs. As usual, the goal of listing host commands is to give a general idea of the information that can be viewed on a host. However, keep in mind that this and other chapters do not attempt to show each variation of every networking command on every OS; instead, the goal is to reinforce the ideas seen earlier in the chapter.

Verifying Host IPv6 Connectivity from Hosts

Most end-user OSs support a convenient way to look at IPv6 settings from the graphical user interface. In some cases, all four of the key IPv6 host settings can be on the same window, while in other cases, seeing all the settings might require navigation to multiple windows or tabs in the same window.

As an example, Figure 28-11 shows a window from Mac OS X, which lists three of the four IPv6 host settings. The one missing setting, the DNS server setting, is in another tab (as seen near the top of the image).



Configure IPv4: Using DHCP

IPv4 Address: 192.168.1.163

Subnet Mask: 255.255.255.0

DHCP Client ID:

Router: 192.168.1.9

Configure IPv6: Automatically

Router: fe80::5ed9:98ff:fe59:b3fc

IPv6 Address	Prefix...
2001:db8:1111:1:1293:e9ff:fe06:a4b6	64
2001:db8:1111:1:50c0:2cf5:a699:d7ba	64

Figure 28-11. Three IPv6 Settings for Dynamic Address Assignment on Mac OS

Take a moment to look at the details in Figure 28-11's image. The image shows the IPv4 settings at the top, as being learned with DHCP. The lower half of the window shows the IPv6 settings as having been learned "Automatically," which means that the host will use either stateful DHCP or SLAAC. In this case, the host used SLAAC to give itself two IPv6 addresses inside the same 2001:DB8:1111:1::/64 subnet—one using EUI-64 rules and one with a random interface ID. (Note that IPv6 host logic includes many details not discussed in this chapter, including the reasons why a host might use two rather than one address.)

Hosts also support a range of commands to check the same information. For IPv6 settings, many OSs use familiar commands: **ipconfig** on Windows OSs and **ifconfig** on Linux and Mac OS. Example 28-2 shows an **ifconfig** command from the same Mac used to create Figure 28-11, for comparison. In particular, if you look at the two highlighted fields, you can see the EUI-64 interface ID that resulted from using this host's MAC address.

Example 28-2. Sample ifconfig **Command from a Mac**

Click here to view code image

```
WOair$ ifconfig en0
en0: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
ether 10:93:e9:06:a4:b6
inet6 fe80::1293:e9ff:fe06:a4b6%en0 prefixlen 64 scopeid 0x4
inet 192.168.1.163 netmask 0xffffff00 broadcast 192.168.1.255
inet6 2001:db8:1111:1:1293:e9ff:fe06:a4b6 prefixlen 64 autoconf
inet6 2001:db8:1111:1:50c0:2cf5:a699:d7ba prefixlen 64 autoconf temporary
media: autoselect
status: active
```

Beyond simply checking the four key IPv6 settings on the host, testing the installation of a new host also requires testing whether the host has connectivity to the rest of the internetwork, using the usual tools: the **ping** and **traceroute** commands.

As for the commands themselves, some OSs (notably Microsoft Windows variants and Cisco routers and switches) let you use the same **ping** and **traceroute** commands used with IPv4. Some other OSs require a different command, like the **ping6** and **traceroute6** commands used with Mac OS and Linux. (The upcoming examples show both variations.)

As for the output of the **ping** and **traceroute** commands, most people who understand the IPv4 version of these commands need no coaching whatsoever to understand the IPv6 version. The output is mostly unchanged compared to the IPv4 equivalents, other than the obvious differences with listing IPv6 addresses. For comparison, upcoming Examples 28-3 and 28-4 show sample output, using the internetwork displayed in Figure 28-12.

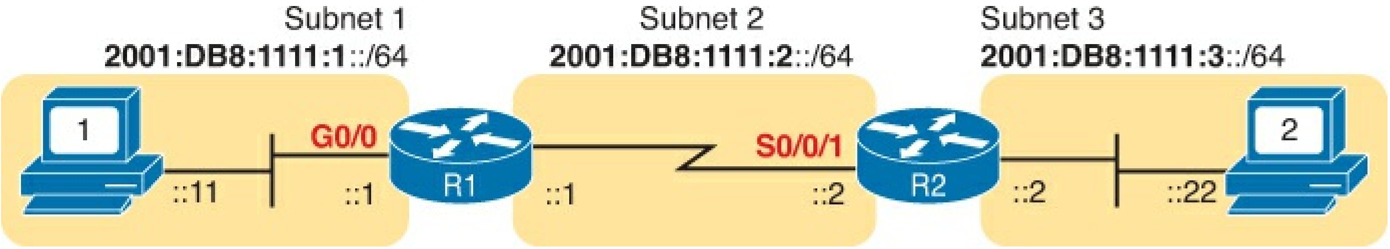


Figure 28-12. Sample IPv6 Internetwork for *ping* and *traceroute* Examples

Example 28-3 shows three **ping** commands, taken from PC1, a Linux host. (Linux happens to replace the older commands with the **ping6** and **traceroute6** commands.) The first two commands show IPv6 pings, the first to R1's LAN IPv6 address, followed by PC1 pinging PC2's IPv6 address. The final command shows an IPv4 ping for comparison.

Example 28-3. The ping6 **Command from PC1, for R1 and PC2**

Click here to view code image

```
Master@PC1:$ ping6 2001:db8:1111:1::1
PING 2001:db8:1111:1::1 (2001:db8:1111:1::1) 56 data bytes
64 bytes from 2001:db8:1111:1::11: icmp_seq=1 ttl=64 time=1.26 ms
64 bytes from 2001:db8:1111:1::11: icmp_seq=2 ttl=64 time=1.15 ms
^C
--- 2001:db8:1111:1::1 ping statistics ---
2 packets transmitted, 2 received, 0% packet loss, time 1001 ms
rtt min/avg/max/mdev = 1.156/1.210/1.263/0.062 ms

Master@PC1:$ ping6 2001:db8:1111:3::22
PING 2001:db8:1111:3::22 ( 2001:db8:1111:3::22) 56 data bytes
64 bytes from 2001:db8:1111:3::22: icmp_seq=1 ttl=64 time=2.33 ms
64 bytes from 2001:db8:1111:3::22: icmp_seq=2 ttl=64 time=2.59 ms
64 bytes from 2001:db8:1111:3::22: icmp_seq=3 ttl=64 time=2.03 ms
^C
--- 2001:db8:1111:3::22 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2003 ms
rtt min/avg/max/mdev = 2.039/2.321/2.591/0.225 ms

! An IPv4 ping next, for comparison - ping of PC2 from PC1
Master@PC1:$ ping 10.1.3.22
PING 10.1.3.22 (10.1.3.22) 56 data bytes
64 bytes from 10.1.3.22: icmp_seq=1 ttl=64 time=2.45 ms
64 bytes from 10.1.3.22: icmp_seq=2 ttl=64 time=2.55 ms
64 bytes from 10.1.3.22: icmp_seq=3 ttl=64 time=2.14 ms
^C
--- 10.1.3.22 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2014 ms
rtt min/avg/max/mdev = 2.04/2.318/2.604/0.224 ms
```

Example 28-4 shows a **traceroute6** command on PC1, finding the route to PC2. The output mirrors the style of output for most IPv4 **traceroute** commands, other than the obvious difference of listing IPv6 addresses. Note that the output lists R1's G0/0 IPv6 address, then R2's S0/0/1 IPv6 address, and then finally PC2's address to end the output.

Example 28-4. The traceroute6 **Command from PC1, for PC2**

Click here to view code image

```
Master@PC1:$ traceroute6 2001:db8:1111:3::22
traceroute to 2001:db8:1111:3::22 (2001:db8:1111:3::22) from 2001:db8:1111:1::11,
30 hops max, 24 byte packets
1 2001:db8:1111:1::1 (2001:db8:1111:1::1) 0.794 ms 0.648 ms 0.604 ms
2 2001:db8:1111:2::2 (2001:db8:1111:2::2) 1.606 ms 1.49 ms 1.497 ms
3 2001:db8:1111:3::22 (2001:db8:1111:3::22) 2.038 ms 1.911 ms 1.899 ms
```

Verifying Host Connectivity from Nearby Routers

For router verification commands for IPv6, some IPv6 features use the exact same command as with IPv4, but some substitute "ipv6" for "ip." And in some cases, particularly with functions that do not exist in IPv4 or have changed quite a bit, routers support brand new commands. This section looks at a couple of router commands useful to verify IPv6 host connectivity, some old and some new for IPv6.

First, for the more familiar commands. Cisco routers and switches support the **ping** and **traceroute** commands with the same basic features for IPv6 as with IPv4. For the standard version of the commands, the commands accept either an IPv4 or an IPv6 address as input. For the extended versions of these commands, the first prompt question asks for the protocol—just type **ipv6**, instead of using the default of **ip**, and answer the rest of the questions.

Of course, an example helps, particularly for the extended commands. Example 28-5 begins with an extended IPv6 **ping**, from R1 to PC2, using R1's G0/0 interface as the source of the packets. The second command shows a standard IPv6 **traceroute** from R1 to PC2.

Example 28-5. Extended ping **and Standard** traceroute **for IPv6 from Router R1**

Click here to view code image

```
R1# ping
Protocol [ip]: ipv6
Target IPv6 address: 2001:db8:1111:3::22
Repeat count [5]:
Datagram size [100]:
Timeout in seconds [2]:
Extended commands? [no]: yes
Source address or interface: GigabitEthernet0/0
UDP protocol? [no]:
Verbose? [no]:
Precedence [0]:
DSCP [0]:
Include hop by hop option? [no]:
Include destination option? [no]:
Sweep range of sizes? [no]:
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 2001:DB8:1111:3::22, timeout is 2 seconds:
Packet sent with a source address of 2001:DB8:1111:1::1
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 0/1/4 ms

R1# traceroute 2001:db8:1111:3::22
Type escape sequence to abort.
Tracing the route to 2001:DB8:1111:3::22

1 2001:DB8:1111:2::2 4 msec 0 msec 0 msec
2 2001:DB8:1111:3::22 0 msec 4 msec 0 msec
```

Another way to verify host settings from a router is to look at the router's neighbor table. All IPv6 hosts, routers included, keep an IPv6 neighbor table: a list of all neighboring IPv6 addresses and matching MAC addresses. Basically, this table replaces the IPv4 ARP table, and it contains the content learned with NDP NS and NA messages.

One way to verify whether a neighboring host is responsive is to find out whether it will send back an NDP NA when the router sends it an NDP NS (to discover the host's MAC address). To do so, the router could clear its neighbor table (**clear ipv6 neighbor**) and then ping a host on some connected interface. The router will first need to send an NDP NS, and the host must send an NDP NA back. If the router shows that host's MAC address in the neighbor table, then the host must have just replied with an NDP NS. Example 28-6 shows a sample of an IPv6 neighbor table, from Router R2 in upcoming Figure 28-13, using the

show ipv6 neighbors command.

Example 28-6. The show ipv6 neighbors **Command on Router R2**

Click here to view code image

```
R2# show ipv6 neighbors
IPv6 Address Age Linklayer Addr State Interface
FE80::11FF:FE11:1111 0 0200.1111.1111 STALE Gi0/0
FE80::22FF:FE22:2222 1 0200.2222.2222 STALE Gi0/0
2001:DB8:1111:3::22 0 0200.2222.2222 REACH Gi0/0
FE80::FF:FE00:3333 1 0200.0000.3333 DELAY Gi0/0
2001:DB8:1111:3::33 0 0200.1111.1111 REACH Gi0/0
2001:DB8:1111:3::3 0 0200.0000.3333 REACH Gi0/0
```

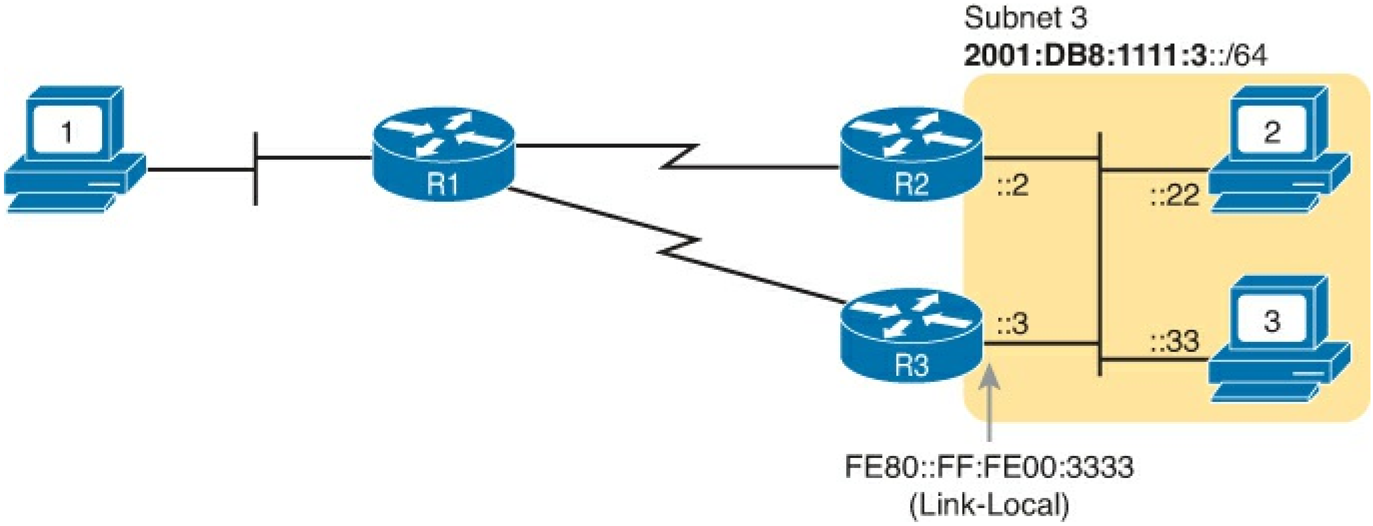


Figure 28-13. Sample IPv6 Internetwork with Two Routers on the Same Link (VLAN)

Finally, routers can also list information about the available routers on a LAN subnet, which impacts the connectivity available to hosts. As a reminder, routers send NDP RA messages to announce their willingness to act as an IPv6 router on a particular LAN subnet. Cisco routers watch for RA messages received from other routers (routers send periodic unsolicited RA messages, by the way). The **show ipv6 routers** command lists any other routers, but not the local router.

As an example, consider the topology shown in Figure 28-13. R1 is the only IPv6 router on the LAN on the left, so R1 does not hear an RA messages from other routers on that LAN subnet. However, R2 and R3, connected to the same subnet, hear NDP RA's from each other. Example 28-7 lists the output of the **show ipv6 routers** command on R1 (with no routers listed) and R2 (with one router listed) for comparison's sake.

Example 28-7. Listing All Routers with the show ipv6 routers **Command**

Click here to view code image

```
! No routers listed by this command on R1
R1# show ipv6 routers
```

```
R1#
! The next command happens on R2 - one router (R3) listed
R2# show ipv6 routers
Router FE80::FF:FE00:3333 on GigabitEthernet0/0, last update 0 min
Hops 64, Lifetime 1800 sec, AddrFlag=0, OtherFlag=0, MTU=1500
HomeAgentFlag=0, Preference=Medium
Reachable time 0 (unspecified), Retransmit time 0 (unspecified)
Prefix 2001:DB8:1111:3::/64 onlink autoconfig
Valid lifetime 2592000, preferred lifetime 604800
```

Finally, one last thought related to commands on hosts themselves: The host can of course list its own NDP information. Interestingly, most hosts list the neighbor table, and then just flag which entries also happen to be routers (the ones that also sent an NDP RA at some point).

Example 28-8 shows an example, this time from a host using Mac OS. Of the two highlighted entries, the first, with the flags field ("Flgs") listing an "R," is a router that formerly sent an RA to announce itself. The second highlighted entry is for a host, so the letter "R" is not listed under the "Flgs" (flags) heading.

Example 28-8. Example NDP Neighbor Table, Mac OS

Click here to view code image

```
WOAir$ ndp -an
Neighbor Linklayer Address Netif Expire St Flgs Prbs
::1 (incomplete) lo0 permanent R
2001:db8:1111:1::1 5c:d9:98:59:b3:fc en0 1s D R
2001:db8:1111:1:1293:e9ff:fe06:a4b6 10:93:e9:6:a4:b6 en0 5s R
```

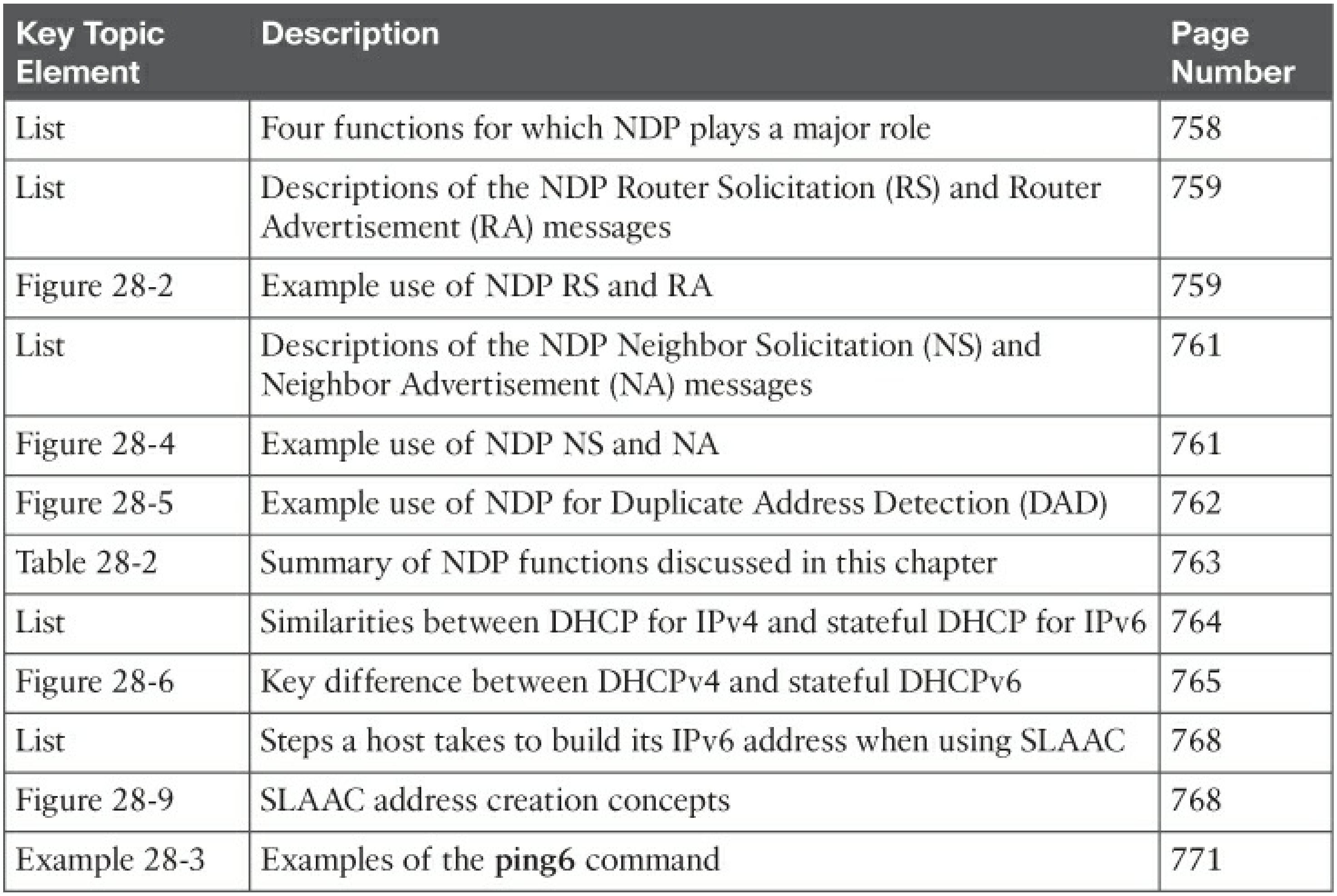
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 28-4 lists these key topics and where each is discussed.

Key Topic

Table 28-4. Key Topics for Chapter 28



Key Topic Element	Description	Page Number
List	Four functions for which NDP plays a major role	758
List	Descriptions of the NDP Router Solicitation (RS) and Router Advertisement (RA) messages	759
Figure 28-2	Example use of NDP RS and RA	759
List	Descriptions of the NDP Neighbor Solicitation (NS) and Neighbor Advertisement (NA) messages	761
Figure 28-4	Example use of NDP NS and NA	761
Figure 28-5	Example use of NDP for Duplicate Address Detection (DAD)	762
Table 28-2	Summary of NDP functions discussed in this chapter	763
List	Similarities between DHCP for IPv4 and stateful DHCP for IPv6	764
Figure 28-6	Key difference between DHCPv4 and stateful DHCPv6	765
List	Steps a host takes to build its IPv6 address when using SLAAC	768
Figure 28-9	SLAAC address creation concepts	768
Example 28-3	Examples of the **ping6** command	771

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix M, “Memory Tables,” or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, “Memory Tables Answer Key,” includes completed tables and lists to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 30 directs you in how to use these terms for late-stage preparation for the exam.

Neighbor Discovery Protocol (NDP)
Router Solicitation (RS)
Router Advertisement (RA)
Neighbor Solicitation (NS)
Neighbor Advertisement (NA)
Stateless Address Autoconfiguration (SLAAC)
Duplicate Address Detection (DAD)
stateful DHCPv6
stateless DHCPv6
IPv6 neighbor table

Command Reference to Check Your Memory

Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To check to see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table with a piece of paper, read the descriptions on the right side, and see whether you remember the command.

Table 28-5. Chapter 28 Configuration Command Reference

Command	Description
ipv6 dhcp relay destination *server-address*	Interface subcommand that enables the IPv6 DHCP relay agent

Table 28-6. Chapter 28 EXEC Command Reference

Command	Description
ping {*host-name* | *ipv6-address*}	Tests IPv6 routes by sending an ICMP packet to the destination host
traceroute {*host-name* | *ipv6-address*}	Tests IPv6 routes by discovering the IP addresses of the routes between a router and the listed destination
show ipv6 neighbors	Lists the router's IPv6 neighbor table
show ipv6 routers	Lists any neighboring routers that advertised themselves through an NDP RA message

Table 28-7. Chapter 28 Host Command Reference

Command (Microsoft, Apple, Linux)	Description
ipconfig / ifconfig / ifconfig	Lists interface settings, including IPv4 and IPv6 addresses
ping / ping6 / ping6	Tests IP routes by sending an ICMPv6 packet to the destination host
tracert / traceroute6 / traceroute6	Tests IP routes by discovering the IPv6 addresses of the routes between a router and the listed destination
netsh interface ipv6 show neighbors / ndp -an / ip -6 neighbor show	Lists a host's IPv6 neighbor table

Chapter 29. Implementing IPv6 Routing

This chapter covers the following exam topics:

- **IP addressing (IPv4 / IPv6)**
  - Describe the technological requirements for running IPv6 in conjunction with IPv4 such as dual stack
- **IP Routing Technologies**
  - Verify router configuration and network connectivity
    - Cisco IOS commands to review basic router information and network connectivity
  - Configure and verify routing configuration for a static or default route given specific routing requirements
  - Differentiate methods of routing and routing protocols
    - Static vs. Dynamic
    - Passive interfaces
  - Configure and verify OSPF (single area)
    - Benefit of single area
    - Configure OSPF v3
    - Router ID
    - Passive interface

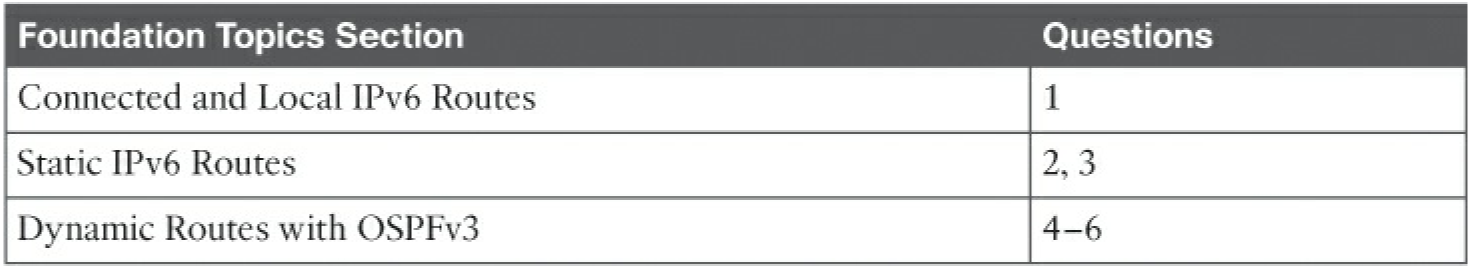
The one remaining piece of the IPv6 story for this book is how routers learn IPv6 routes. The easiest and most common way to make all routers learn all the correct routes is to use a dynamic IPv6 routing protocol, like Open Shortest Path First (OSPF) version 3 (OSPFv3). So, this chapter discusses the basics of OSPFv3 implementation, in the third major section of this chapter.

However, so far this book has not yet discussed other simpler ways that routers can add IPv6 routes to their routing tables: connected, local, and static routes. The first section of this chapter walks you through the details of how IPv6, similar to IPv4, adds both connected and local routes based on each interface IPv6 address. The second major section of this chapter then looks at how to configure static IPv6 routes by typing in commands, in this case using the **ipv6 route** command instead of IPv4's **ip route** command.

"Do I Know This Already?" Quiz

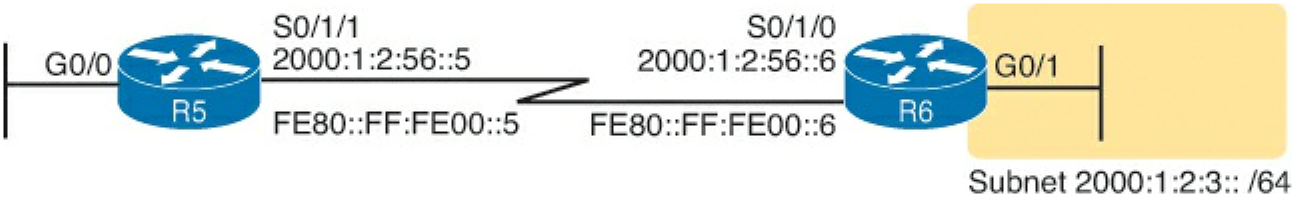
Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 29-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Connected and Local IPv6 Routes	1
Static IPv6 Routes	2, 3
Dynamic Routes with OSPFv3	4–6

1. A router has been configured with the **ipv6 address 2000:1:2:3::1/64** command on its G0/0 interface. The router creates a link-local address of FE80::FF:FE00:1 as well. The interface is working. Which of the following routes will the router add to its IPv6 routing table? (Choose two answers.)



   a. A route for 2000:1:2:3::/64
   b. A route for FE80::FF:FE00:1/64
   c. A route for 2000:1:2:3::1/128
   d. A route for FE80::FF:FE00:1/128

2. An engineer needs to add a static IPv6 route for prefix 2000:1:2:3::/64 to Router R5, in the figure shown with the previous question. Which of the following answers shows a valid static IPv6 route for that subnet, on Router R5?

   a. ipv6 route 2000:1:2:3::/64 S0/1/1
   b. ipv6 route 2000:1:2:3::/64 S0/1/0

c. **ip route 2000:1:2:3::/64 S0/1/1**

d. **ip route 2000:1:2:3::/64 S0/1/0**

3. An engineer needs to add a static IPv6 route for prefix 2000:1:2:3::/64 to Router R5 in the figure shown with Question 1. Which of the following answers shows a valid static IPv6 route for that subnet, on Router R5?

a. **ipv6 route 2000:1:2:3::/64 2000:1:2:56::5**

b. **ipv6 route 2000:1:2:3::/64 2000:1:2:56::6**

c. **ipv6 route 2000:1:2:3::/64 FE80::FF:FE00:5**

d. **ipv6 route 2000:1:2:3::/64 FE80::FF:FE00:6**

4. An engineer needs to add IPv6 support to an existing router, R1. R1 already has IPv4 and OSPFv2 implemented on all interfaces. The new project requires the addition of IPv6 addresses and OSPFv3 on all interfaces. Which of the following answers list a command that must be part of the completed configuration to support IPv6 and OSPFv3? (Choose two answers.)

a. The **ipv6 router ospf** *process-id* global command

b. The **router-id** command in OSPFv3 configuration mode

c. The **network** *prefix/length* command in OSPFv3 configuration mode

d. The **ipv6 ospf** *process-id* **area** *area-id* command on each IPv6-enabled interface

5. Which of the following commands list the interfaces on which OSPFv3 has been enabled? (Choose two answers.)

a. **show ipv6 ospf database**

b. **show ipv6 ospf interface brief**

c. **show ipv6 ospf**

d. **show ipv6 protocols**

6. Which of the following answers list a routing protocol that advertises IPv6 routes? (Chooses two answers.)

a. OSPFv6

b. OSPFv3

c. EIGRPv6

d. EIGRPv3

Answers to the "Do I Know This Already?" quiz:

1 A and C **2** A **3** B **4** A and D **5** B and D **6** B and C

Foundation Topics

Connected and Local IPv6 Routes

A Cisco router adds IPv6 routes to its IPv6 routing table for several reasons. Many of you could predict those reasons at this point in your reading, in part because the logic mirrors the logic routers use for IPv4. Specifically, a router adds IPv6 routes based on the following:

- The configuration of IPv6 addresses on working interfaces (connected and local routes)
- The direct configuration of a static route (static routes)
- The configuration of a routing protocol, like OSPFv3, on routers that share the same data link (dynamic routes, in this case, OSPF routes)

The three sections of this chapter follow this same outline, and in the same order.

Rules for Connected and Local Routes

Routers add and remove connected routes, and local routes, based on the interface configuration and the interface state. First, the router looks for any configured unicast addresses on any interfaces by looking for the **ipv6 address** command. Then, if the interface is working—if the interface has a "line status is up, protocol status is up" notice in the output of the **show interfaces** command—the router adds both a connected and local route.

> **Note**
>
> Routers do not create IPv6 routes for link-local addresses.

The connected and local routes themselves follow the same general logic as with IPv4. The connected route represents the subnet connected to the interface, while the local route is a host route for only the specific IPv6 address configured on the interface.

As an example, consider a router, with a working interface, configured with the **ipv6 address 2000:1:1:1::1/64** command. The router will calculate the subnet ID based on this address and prefix list, and place a connected route for that subnet (2000:1:1:1::/64) into the routing table. The router also takes the listed IPv6 address and creates a host route for that address, with a *128 prefix length. (With IPv4, host routes have a* 32 prefix length, while IPv6 uses a /128 prefix length, meaning "exactly this one address.")

Key Topic

The following list summarizes these rules for easier review and study:

1. Routers create IPv6 routes based each unicast IPv6 address on an interface, as configured with the **ipv6 address** command, as follows:
   - **A.** The router creates a route for the subnet (a connected route).
   - **B.** The router creates a host route (/128 prefix length) for the router IPv6 address (a local route).
2. Routers do not create routes based on the link-local addresses associated with the interface.
3. Routers remove the connected and local routes for an interface if the interface fails, and re-adds these routes when the interface is again in a working (up/up) state.

Example of Connected IPv6 Routes

While the concept of connected and local IPv6 routes works muck like IPv4 routes, seeing a few examples can certainly help. To show some example routes, Figure 29-1 gives the details of one sample internetwork used in this chapter. The figure shows the IPv6 subnet IDs. The upcoming examples focus on the connected and local routes on Router R1.

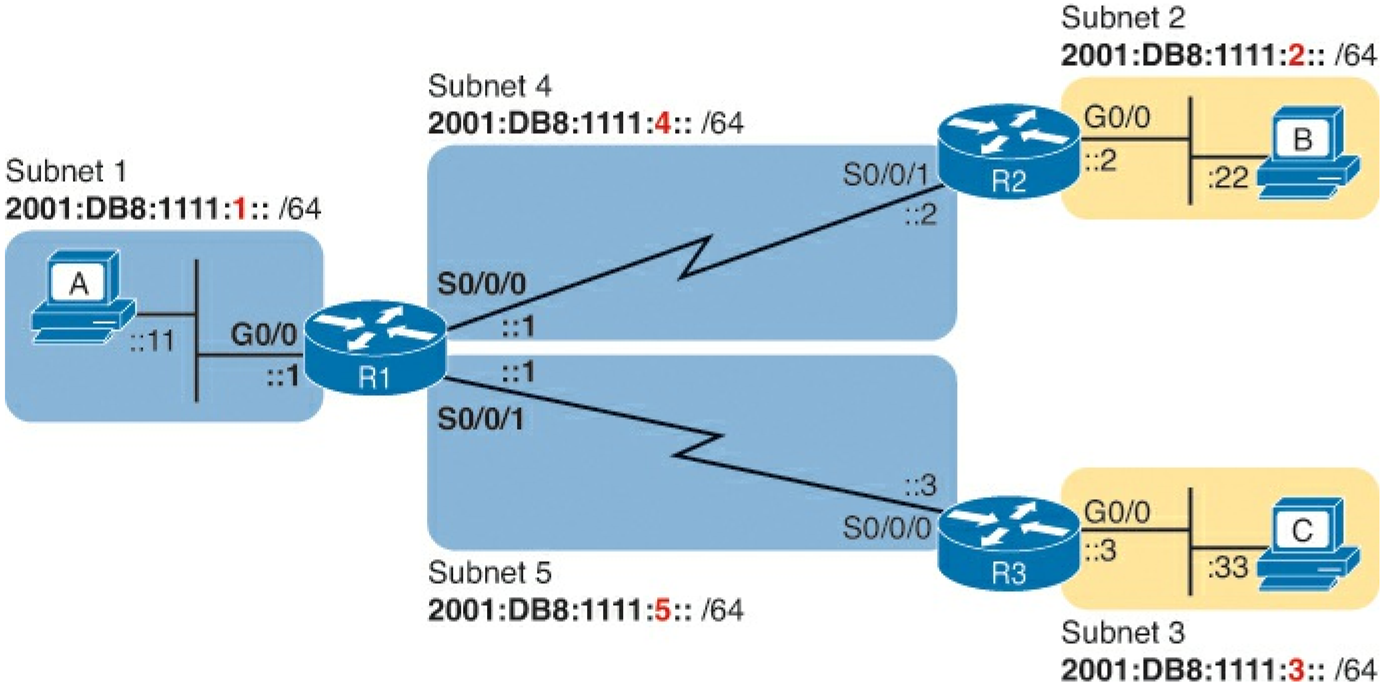


Figure 29-1. Sample Network Used to Show Connected and Local Routes

To clarify the notes in the figure, note that the figure shows IPv6 prefixes (subnets), with a shorthand notation for the interface IPv6 addresses. The figure shows only the abbreviated interface ID portion of each interface address near each interface. For example, R1's G0/0 interface address would begin with subnet ID value 2001:DB8:1111:1, added to ::1, for 2001:DB8:1111:1::1.

Now on to the example of connected routes. To begin, consider the configuration of Router R1 from Figure 29-1, as shown in Example 29-1. The excerpt from the **show running-config** command on R1 shows three interfaces, all of which are working.

Also note that no static route or OSPFv3 configuration exists.

Example 29-1. IPv6 Addressing Configuration on Router R1

Click here to view code image

```
ipv6 unicast-routing
!
interface serial0/0/0
ipv6 address 2001:db8:1111:4::1/64
!
interface serial0/0/1
ipv6 address 2001:db8:1111:5::1/64
!
interface gigabitethernet0/0
ipv6 address 2001:db8:1111:1::1/64
```

Based on Figure 29-1 and Example 29-1, R1 should have three connected IPv6 routes, as highlighted in Example 29-2.

Example 29-2. Routes on Router R1 Before Adding Static or OSPF Routes

Click here to view code image

```
R1# show ipv6 route
IPv6 Routing Table - default - 7 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
B - BGP, R - RIP, I1 - ISIS L1, I2 - ISIS L2
IA - ISIS interarea, IS - ISIS summary, D - EIGRP, EX - EIGRP external
ND - Neighbor Discovery, l - LISP
O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
C 2001:DB8:1111:1::/64 [0/0]
via GigabitEthernet0/0, directly connected
L 2001:DB8:1111:1::1/128 [0/0]
via GigabitEthernet0/0, receive
C 2001:DB8:1111:4::/64 [0/0]
via Serial0/0/0, directly connected
L 2001:DB8:1111:4::1/128 [0/0]
via Serial0/0/0, receive
C 2001:DB8:1111:5::/64 [0/0]
via Serial0/0/1, directly connected
L 2001:DB8:1111:5::1/128 [0/0]
via Serial0/0/1, receive
L FF00::/8 [0/0]
via Null0, receive
```

All three highlighted routes show the same basic kinds of information, so for discussion, focus on the first pair of highlighted lines, which detail the connected route for subnet 2001:DB8:1111:1::/64. Much of the information is self-explanatory: the phrase "directly connected" referring to the fact that the route is a connected route, the interface identifier, and the prefix/length of 2001:DB8:1111:1::/64. At the far left, the code letter "C" identifies the route as a connected route (per the legend above). Also note that the numbers in brackets mirror the same ideas as IPv4's **show ip route** command: The first number represents the administrative distance and the second is the metric.

Examples of Local IPv6 Routes

Continuing this same example, three local routes should exist on R1 for the same three interfaces as the connected routes. Indeed that is the case, with one extra local route for other purposes. Example 29-3 shows only the local routes, as listed by the **show ipv6 route local** command, with highlights of one particular local route for discussion.

Example 29-3. Local IPv6 Routes on Router R1

Click here to view code image

```
R1# show ipv6 route local
! Legend omitted for brevity

L 2001:DB8:1111:1::1/128 [0/0]
```

```
via GigabitEthernet0/0, receive
L 2001:DB8:1111:4::1/128 [0/0]
via Serial0/0/0, receive
L 2001:DB8:1111:5::1/128 [0/0]
via Serial0/0/1, receive
L FF00::/8 [0/0]
via Null0, receive
```

For the highlighted local route, look for a couple of quick facts. First, look back to R1's configuration in Example 29-1, and note R1's IPv6 address on its G0/0 interface. This local route lists the exact same address. Also note the /128 prefix length, meaning this route matches packet sent to that address (2001:DB8:1111:1::1), and only that address.

Static IPv6 Routes

While routers automatically add connected and local routes based on the interface configuration, static routes require direct configuration with the **ipv6 route** command. Simply put, someone configures the command, and the router places the details from the command into a route in the IPv6 routing table.

The **ipv6 route** command follows the same general logic as does IPv4's **ip route** command, as discussed back in Chapter 16, "Configuring IPv4 Addresses and Routes." For IPv4, the **ip route** command starts by listing the subnet ID and mask, so for IPv6, the **ipv6 route** command begins with the prefix and prefix length. Then, the respective commands list the directions of how this router should forward packets towards that destination subnet or prefix, by listing the outgoing interface, or the address of the next-hop router.

Figure 29-2 shows the concepts behind a single **ipv6 route** command, demonstrating the concepts behind a static route on Router R1 for the subnet on the right (subnet 2, or 2001:DB8:1111:2::/64). A static route on R1, for this subnet, will begin with **ipv6 route 2001:DB8:1111:2::/64**, followed by either the outgoing interface (S0/0/0) or the next-hop IPv6 address, or both.

Key Topic

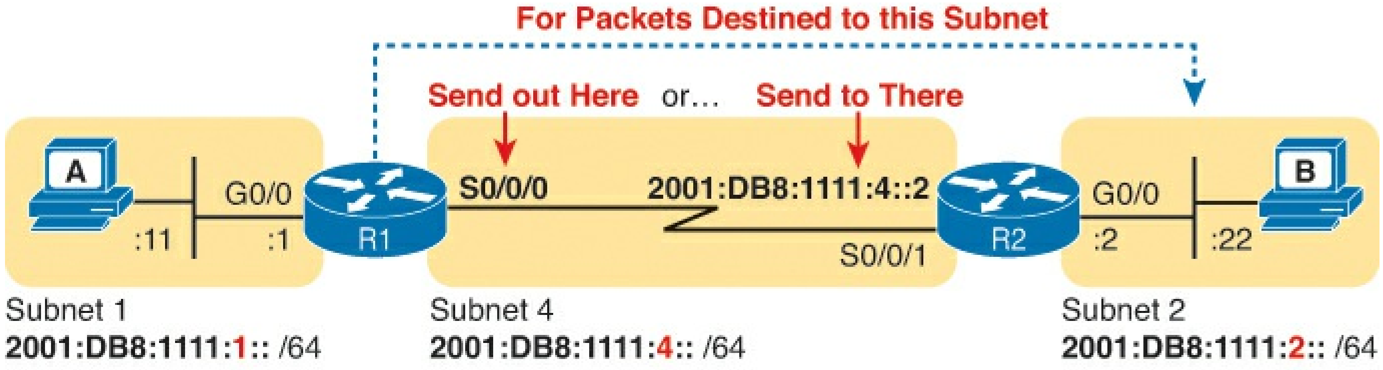


Figure 29-2. Logic Behind IPv6 Static Route Commands (IPv6 route)

Now that you understand the big ideas with IPv6 static routes, the next few pages walk you through a series of examples. In particular, the examples look at configuring static routes with an outgoing interface, then with a next-hop global unicast address, and then with a next-hop link-local address. This section ends with a discussion of static IPv6 default routes.

Static Routes Using the Outgoing Interface

This first IPv6 static route example uses the outgoing interface option. As a reminder, for both IPv4 and IPv6 static routes, when the command references an interface, the interface is a local interface. That is, it is an interface on the router where the command is added. In this case, as shown in Figure 29-2, R1's **ipv6 route** command would use interface S0/0/0, as shown in the top of Example 29-4.

Example 29-4. Static IPv6 Routes on Router R1

Click here to view code image

```
! Static route on router R1
R1(config)# ipv6 route 2001:db8:1111:2::/64 s0/0/0
```

While Example 29-4 shows the correct syntax of the route, if using static routes throughout this internetwork, more static routes are needed. For example, to support traffic between hosts A and B, R1 is now prepared. Host A will forward all its IPv6 packets to its default router (R1), and R1 can now routes those packets out S0/0/0 to R2 next. However, Router R2 does not yet have a route back to host A's subnet, subnet 1 (2001:DB8:1111:1::/64), so a complete solution requires more routes.

Example 29-5 solves this problem by giving Router R2 a static route for subnet 1 (2001:DB8:1111:1:/64). After adding this route, hosts A and B should be able to ping each other.

Example 29-5. Static IPv6 Routes on Router R2

Click here to view code image

```
! Static route on router R2
R2(config)# ipv6 route 2001:db8:1111:1::/64 s0/0/1
```

Many options exist for verifying the existence of the static route and testing whether hosts can use the route. **ping** and **traceroute**, as discussed in Chapter 28, "Implementing IPv6 Addressing on Hosts" can test connectivity. From the router command line, the **show ipv6 route** command will list all the IPv6 routes. The shorter output of the **show ipv6 route static** command, which lists only static routes, could also be used; Example 29-6 shows that output, with the legend omitted.

Example 29-6. Verification of Static Routes Only on R1

Click here to view code image

```
R1# show ipv6 route static
! Legend omitted for brevity
S 2001:DB8:1111:2::/64 [1/0]
via Serial0/0/0, directly connected
```

This command lists many facts about the one static route on R1. First, the code "S" in the left column does identify the route as a static route. (However, the later phrase "directly connected" might mislead you to think this is a connected route; trust the "S" code.) Note that the prefix (2001:DB8:1111:2::/64) matches the configuration (in Example 29-4), as does the outgoing interface (S0/0/0).

While this command lists basic information about each static route, it does not state whether this route would be used when forwarding packets to a particular destination. For example, if host A sent an IPv6 packet to host B (2001:DB8:1111:2::22), would R1 use this static route? As it turns out, the **show ipv6 route 2001:DB8:1111:2::22** command answers this question. This command asks the router to list the route the router would use when forwarding packets to that particular address. Example 29-7 shows an example.

Example 29-7. Displaying the Router R1 Uses to Forward to Host B

Click here to view code image

```
R1# show ipv6 route 2001:db8:1111:2::22
Routing entry for 2001:DB8:1111:2::/64
Known via "static", distance 1, metric 0
Route count is 1/1, share count 0
Routing paths:
directly connected via Serial0/0/0
Last updated 00:01:29 ago
```

Static Routes Using Next-Hop IPv6 Address

Static IPv6 routes that refer to a next-hop address have two options: the unicast address on the neighboring router (global unicast or unique local), or the link-local address of that same neighboring router. Figure 29-3 spells out those two options with an updated version of Figure 29-2, this time showing Router R2's global unicast as well as R2's link-local address.

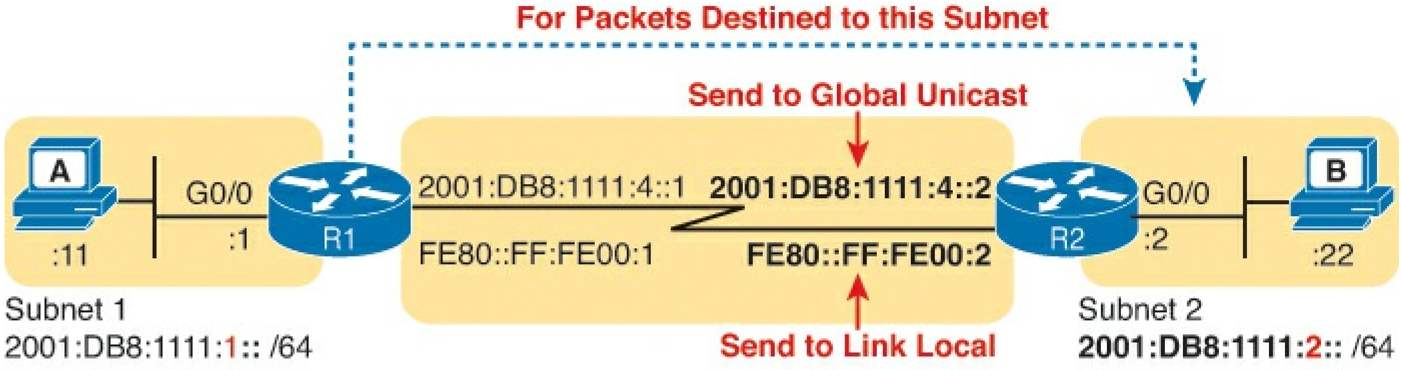


Figure 29-3. Using Unicast or Link-Local as Next-Hop Address for Static Routes

The next few pages walk you through examples, first with a global unicast as next-hop and then with a link-local as next-hop.

Example Static Route with a Global Unicast Next-Hop Address

This example uses the internetwork in Figure 29-3, but with the earlier static routes removed. That is, both routers have only connected and local routes to begin the example.

For this example, as shown in Example 29-8, both R1 and R2 add static routes that refer to the neighbor's global unicast address. R1 adds a route for subnet 2 (on the right), while R2 adds a route for subnet 1 (on the left). Note that the example shows routes in both directions so that the two hosts can send packets to each other.

Example 29-8. Static IPv6 Routes Using Global Unicast Addresses

Click here to view code image

```
! The first command is on router R1, listing R2's global unicast address
R1(config)# ipv6 route 2001:db8:1111:2::/64 2001:DB8:1111:4::2
```

```
! The next command is on router R2, listing R1's global unicast address
R2(config)# ipv6 route 2001:db8:1111:1::/64 2001:db8:1111:4::1
```

The **ipv6 route** command itself is relatively straightforward. Focus on R1's route, which matches the logic shown in Figure 29-3. The command lists subnet 2 (2001:DB8:1111:2::/64). It then lists R2's global unicast address (ending in 4::2).

The verification commands on R1, as shown in Example 29-9, list the usual information. Example 29-9 shows two commands, first listing R1's only static route (the one configured in Example 29-8). The end of the example lists the **show ipv6 route 2001:DB8:1111:2::22** command, which lists the route R1 uses when forwarding packets to Host B, proving that R1 uses this new static route when forwarding packets to that host.

Example 29-9. Verification of Static Routes to a Next-Hop Global Unicast Address

Click here to view code image

```
R1# show ipv6 route static
! Legend omitted for brevity
S 2001:DB8:1111:2::/64 [1/0]
via 2001:DB8:1111:4::2

R1# show ipv6 route 2001:db8:1111:2::22/64
Routing entry for 2001:DB8:1111:2::/64
Known via "static", distance 1, metric 0
Backup from "ospf 1 [110]"
Route count is 1/1, share count 0
Routing paths:
2001:DB8:1111:4::2
Last updated 00:07:43 ago
```

Example Static Route with a Link-Local Next-Hop Address

Static routes that refer to a neighbor's link-local address work a little like both of the previous two styles of static routes. First, the **ipv6 route** command refers to a next-hop address, namely a link-local address. However, the command must also refer to the router's local outgoing interface. Why both? The **ipv6 route** command cannot simply refer to a link-local next-hop address by itself, because the link-local address does not, by itself, tell the local router which outgoing interface to use.

Interestingly, when the **ipv6 route** command refers to a global unicast next-hop address, the router can deduce the outgoing interface. For example, the earlier example on R1, as shown in Example 29-8, shows R1 with a static IPv6 route with a next-hop IPv6 address of 2001:DB8:1111:4::2. R1 can look at its IPv6 routing table, see its connected route that includes this 2001:DB8:1111:4::2 address, and see a connected route off R1's S0/0/0. As a result, with a next-hop global unicast address, R1 can deduce the correct outgoing interface (R1's S0/0/0).

With a link-local next-hop address, a router cannot work through this same logic, so the outgoing interface must also be configured. Example 29-10 shows the configuration of static routes on R1 and R2, replacements for the two routes previously configured in Example 29-8.

Example 29-10. Static IPv6 Routes Using Link-Local Neighbor Addresses

Click here to view code image

```
! The first command is on router R1, listing R2's link-local address
R1(config)# ipv6 route 2001:db8:1111:2::/64 S0/0/0 FE80::FF:FE00:2
```

```
! The next command is on router R2, listing R1's link-local address
R2(config)# ipv6 route 2001:db8:1111:1::/64 S0/0/1 FE80::FF:FE00:1
```

Example 29-11 verifies the configuration in Example 29-10 by repeating the **show ipv6 route static** and **show ipv6 route 2001:DB8:1111:2::22** commands used in Example 29-9. Note that the output from both commands differs slightly in regards to the forwarding details. Because the new commands list both the next-hop address and outgoing interface, the **show** commands also list both the next-hop (link-local) address and the outgoing interface. If you refer back to Example 29-9, you will see only a next-hop address listed.

Example 29-11. Verification of Static Routes to a Next-Hop Link-Local Address

Click here to view code image

```
R1# show ipv6 route static
! Legend omitted for brevity

S 2001:DB8:1111:2::/64 [1/0]
via FE80::FF:FE00:2, Serial0/0/0

R1# show ipv6 route 2001:db8:1111:2::22
Routing entry for 2001:DB8:1111:2::/64
Known via "static", distance 1, metric 0
Backup from "ospf 1 [110]"
Route count is 1/1, share count 0
Routing paths:
FE80::FF:FE00:2, Serial0/0/0
Last updated 00:08:10 ago
```

Static Default Routes

IPv6 supports a default route concept, similar to IPv4. The default route tells the router what to do with an IPv6 packet when the packet matches no other IPv6 route. The logic is pretty basic:

- With no default route, the router discards the IPv6 packet.
- With a default route, the router forwards the IPv6 packet based on the default route.

Default routes can be particularly useful in a couple of network design cases. For example, with an enterprise network design that uses a single router at each branch office, with one WAN link to each branch, the branch routers have only one possible path over which to forward packets. In a large network, when using a routing protocol, the branch router could learn thousands of routes—all of which point back toward the core of the network over that one WAN link.

Branch routers could use default routes instead of a routing protocol. The branch router would forward all traffic to the core of the network. Figure 29-4 shows just such an example, with two sample branch routers on the right and a core site router on the left.

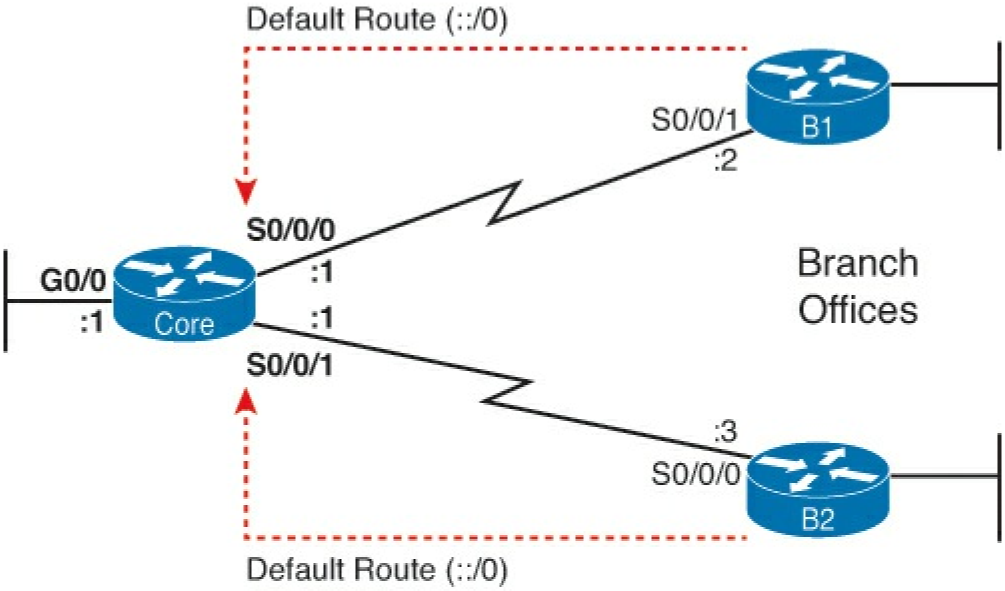


Figure 29-4. Using Static Default Routes at Branches to Forward Back to the Core

To configure a static default route, use the same rules already discussed in this section of the chapter, but use a specific value to note the route as a default route: ::/0. Taken literally, the double colon (::) is the IPv6 abbreviation for all 0s, and the *0 means the prefix length is 0. This idea mirrors the IPv4 convention to refer to the default route as 0.0.0.0*0. Otherwise, just configure the **ipv6 route** command as normal.

Example 29-12 shows one such example static default route on Router B1 from Figure 29-4. This example uses the outgoing interface option.

Example 29-12. Static Default Route for Branch Router B1

Click here to view code image

```
!Forward out B1's S0/0/1 local interface...
B1(config)# ipv6 route ::/0 S0/0/1
```

With IPv6, the router displays the default a little more cleanly than with IPv4. The **show ipv6 route** command simply includes the route in the output of the command, along with the other routes. Example 29-13 shows an example, with "::/0" listed to denote this route as the default route.

Example 29-13. Router B1's Static Default Route (Using Global Unicast Next-Hop)

Click here to view code image

```
B1# show ipv6 route static
IPv6 Routing Table - default - 10 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
B - BGP, R - RIP, I1 - ISIS L1, I2 - ISIS L2
IA - ISIS interarea, IS - ISIS summary, D - EIGRP, EX - EIGRP external
ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
S ::/0 [1/0]
via Serial0/0/1, directly connected
```

Dynamic Routes with OSPFv3

While static routes work, most internetworks use a dynamic routing protocol to learn the IPv6 routes for all subnets not connected to a local router. This last major section of the chapter looks at one IPv6 routing protocol—OSPF version 3—focusing on the similarities with OSPF version 2 and the configuration.

This section begins by working through some conceptual and theoretical details about OSPF version 3 (OSPFv3). After going through a short discussion of theory, this section walks you through the configuration, which is both different and simpler than the equivalent OSPFv2 configuration for IPv4. This section ends with many examples of **show** commands to find out if OSPFv3 is working correctly, learning IPv6 routes.

Comparing OSPF for IPv4 and IPv6

As you might expect, OSPFv3—the version of OSPF that supports IPv6—works a lot like OSPFv2, which supports IPv4. The next few pages work through some of the terminology, concepts, similarities, and differences in how OSPF works for IPv6 versus IPv4.

OSPF Routing Protocol Versions and Protocols

First, when most engineers refer to "OSPF," they most likely refer to OSPF as used with IPv4, and specifically, OSPF version 2 (OSPFv2). Once, there was an OSPF version 1, but OSPF version 2 (OSPFv2) followed soon afterward. When OSPF became widely used as an IPv4 routing protocol, back in the early to mid 1990s, everyone used OSPFv2 and not OSPFv1. So, even in the early days of OSPF, there was no need for people to talk about whether they used OSPFv1 or OSPFv2; everyone used OSPFv2 and just called it OSPF.

Next, consider the development of the original IPv6 protocols, back in early to mid 1990s. Beyond IPv6 itself, many other protocols needed to be updated to make IPv6 work: ICMP, TCP, UDP, and so on, including OSPF. When a working group updated OSPF to support IPv6, what did they call it? OSPF version 3, of course.

Interestingly, OSPFv3 supports advertising IPv6 routes, but not IPv4 routes. So, OSPFv3 does not attempt to add IPv6 support to the preexisting OSPFv2. While the protocols share many similarities, think of OSPFv2 and OSPFv3 as different routing protocols: one for IPv4 routes (OSPFv2) and one for IPv6 routes (OSPFv3).

Because OSPFv3 advertises IPv6 routes, and only IPv6 routes, an enterprise network that uses a dual-stack strategy actually needs to run both OSPFv2 and OSPFv3 (assuming they use OSPF at all). Are their underlying concepts very similar? Yes. However, each router would run both an OSPFv2 and OSPFv3 routing protocol process, with both processes forming neighbor relationships, both sending database updates, and both calculating routes. So, a typical migration from an OSPFv2, IPv4-only enterprise network, to instead support a dual-stack IPv4/IPv6 approach (running both IPv4 and IPv6 on each host/router), would use these basic steps:

Step 1. Before IPv6, the company supports IPv4 using OSPFv2.

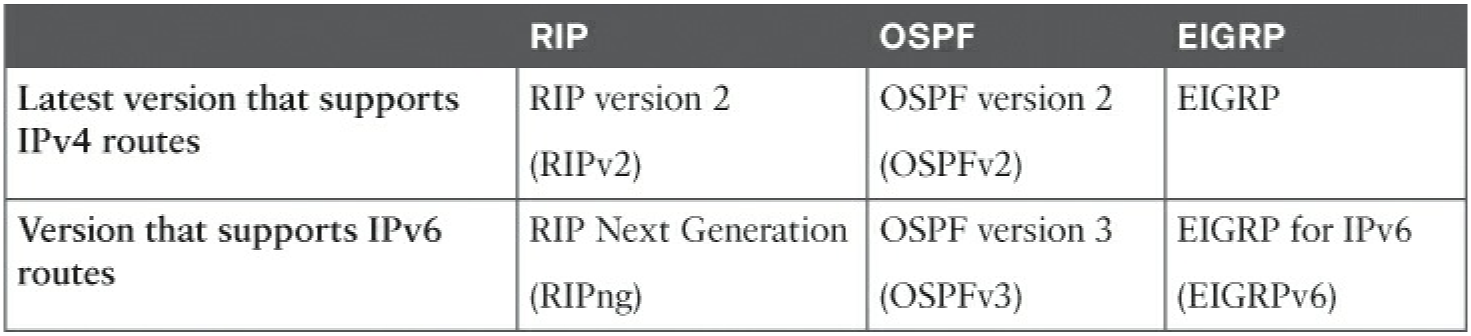
Step 2. When planning to add IPv6 support, the company plans to use a dual-stack approach, supporting both IPv4 and IPv6 routing on the routers in the enterprise network.

Step 3. To support IPv6 routing, companies add OSPFv3 configuration to all the routers, but they must keep the OSPFv2 configuration to continue to route IPv4 packets.

Other routing protocols followed a similar progression for updates to support IPv6, although with more unusual names. In the case of Routing Information Protocol (RIP), RIP has two versions that support IPv4, with the expected names of RIP version 1 (RIPv1) and RIP version 2 (RIPv2). To support IPv6, a working group created a new version of RIP, called *RIP Next Generation (RIPng)*, with the name chosen in reference to the "Star Trek" TV series. (Yep.) Enhanced Interior Gateway Routing Protocol (EIGRP), as a Cisco-proprietary routing protocol, has always been known simply as "EIGRP." However, to make discussions easier, some documents refer to EIGRP IPv4 support as "EIGRP," and EIGRP for IPv6 as "EIGRPv6."

Table 29-2 summarizes the terminology for these main three interior IP routing protocols.

Table 29-2. Summary of Version Terminology for Interior Routing Protocols



	RIP	OSPF	EIGRP
Latest version that supports IPv4 routes	RIP version 2 (RIPv2)	OSPF version 2 (OSPFv2)	EIGRP
Version that supports IPv6 routes	RIP Next Generation (RIPng)	OSPF version 3 (OSPFv3)	EIGRP for IPv6 (EIGRPv6)

Comparing OSPFv2 and OSPFv3

To the depth that this book discusses OSPF theory and concepts, OSPFv3 acts very much like OSPFv2. For example, both use link-state logic. Both use the same metric. And the list keeps getting longer, because the protocols do have many similarities. The following list notes many of the similarities for the features discussed both in this chapter in Chapter 17, "Learning IPv4 Routes with OSPFv2":

Key Topic

- Both are link-state protocols.
- Both use the same area design concepts and design terms.
- Both require that the routing protocol be enabled on an interface.
- Once enabled on an interface, both then attempt to discover neighbors connected to the data link connected to an interface.
- Both perform a check of certain settings before a router will become neighbors with another router (the list of checks is slightly different between OSPFv2 and OSPFv3).
- After two routers become neighbors, both OSPFv2 and OSPFv3 proceed by exchanging the contents of their link-state databases (LSDB)—the link-state advertisements (LSA) that describe the network topology—between the two neighbors.
- After all the LSAs have been exchanged, both OSPFv2 and OSPFv3 use the shortest path first (SPF) algorithm to calculate the best route to each subnet.
- Both use the same metric concept, based on the interface cost of each interface, with the same default cost values.
- Both use LSAs to describe the topology, with some differences in how LSAs work.

The biggest differences between OSPFv3 and the older OSPFv2 lay with internals and with configuration. OSPFv3 changes the structure of some OSPF LSAs; however, these differences do not sit within the scope of this book. OSPFv3 uses a more direct approach to configuration, enabling OSPFv3 on each interface using an interface subcommand.

For later comparison to OSPFv3 configuration, Figure 29-5 shows the structure of the configuration for OSPFv2. It shows the fact that the OSPFv2 **network** subcommand—a subcommand in router configuration mode—refers to the IPv4 address on an interface, which then identifies the interface on which OSPFv2 should be enabled. In other words, the OSPFv2 configuration does not mention the interface directly.

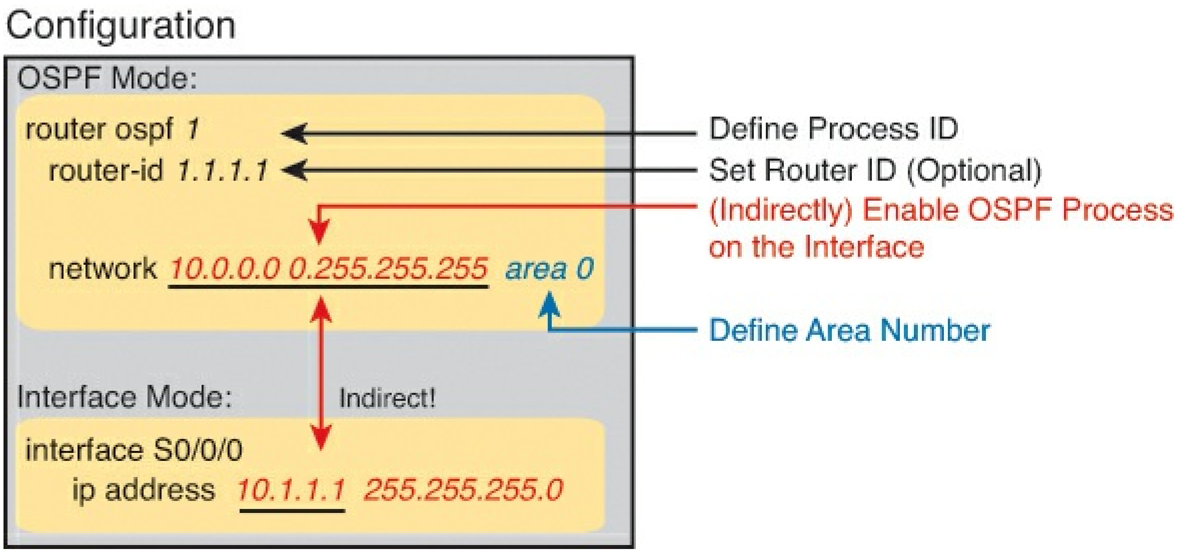

Configuration
OSPF Mode:
router ospf 1
router-id 1.1.1.1
network 10.0.0.0 0.255.255.255 area 0
Define Process ID
Set Router ID (Optional)
(Indirectly) Enable OSPF Process on the Interface
Define Area Number
Interface Mode:
Indirect!
interface S0/0/0
ip address 10.1.1.1 255.255.255.0

Figure 29-5. OSPFv2 Indirectly Enables OSPF on the Interface

OSPFv3 configuration directly enables OSPF on the interface by adding a subcommand in interface configuration mode to enable OSPFv3 on that interface. In fact, OSPFv3 does not use a **network** subcommand in router configuration mode. Instead, OSPFv3 uses the **ipv6 ospf** *process-id* **area** *area-id* interface subcommand, as shown in Figure 29-6. This command enables the listed OSPFv3 process on that interface, and sets the OSPFv3 area.

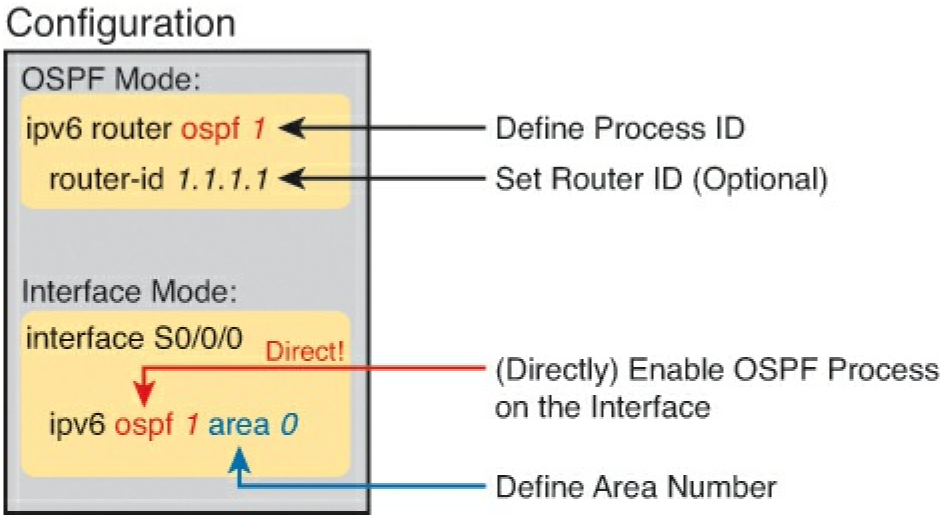

Configuration
OSPF Mode:
ipv6 router ospf 1
router-id 1.1.1.1
Define Process ID
Set Router ID (Optional)
Interface Mode:
interface S0/0/0
Direct!
ipv6 ospf 1 area 0
(Directly) Enable OSPF Process on the Interface
Define Area Number

Figure 29-6. OSPFv3 Configuration Directly Enables OSPF on the Interface

> **Note**
>
> Cisco IOS actually supports configuration of OSPFv2 using the same style of commands shown for OSPFv3 in Figure 29-6 as well. IOS supports only the new, more direct configuration style for OSPFv3, as shown in the figure.

Now that you have a general idea about the similarities and differences between OSPFv3 and OSPFv2, the rest of this section shows examples of how to configure and verify OSPFv3.

Configuring Single-Area OSPFv3

OSPFv3 configuration requires some basic steps: pick and configure a process ID, and enable the process on each interface, while assigning the correct OSPF area to each interface. These details should be listed in any planning information. Also, this book uses single-area designs only, so all the interfaces should be assigned to the same area.

The one potential configuration issue is the OSPFv3 router ID (RID).

For review, OSPFv2 uses a 32-bit RID, chosen when the OSPF process initializes. That is, when OSPF is first configured, or later, when the router is reloaded, the OSPFv2 process chooses a number to use as its RID. When choosing the OSPFv2 process chooses its RID based using this list until it finds a RID:

Key Topic

1. If the **router-id** *rid* OSPF subcommand is configured, use this value, and ignore interface IPv4 addresses.

2. If the router ID is not set with the **router-id** command, check any loopback interfaces that have an IPv4 address configured and an interface status of up. Among these, pick the highest numeric IP address.
3. If neither of the first two items supply a router ID, the router picks the highest numeric IPv4 address from all other interfaces whose interface status code (first status code) is up. (In other words, an interface is up/down state will be included by OSPF when choosing its router ID.)

Interestingly, OSPFv3 also uses a 32-bit RID, using the exact same rules as OSPFv2. The number is typically listed in dotted-decimal notation (DDN). That is, OSPFv3, which supports IPv6, has a router ID that looks like an IPv4 address.

Using the same RID selection rules for OSPFv3 as for OSPFv2 leaves open one unfortunate potential misconfiguration: a router that does not use the OSPFv3 **router-id** command, and does not have any IPv4 addresses configured, cannot choose a RID. If the OSPFv3 process does not have an RID, the process cannot work correctly, form neighbor relationships, or exchange routes.

This problem can be easily solved. When configuring OSPFv3, if the router does not have any IPv4 addresses, make sure to configure the RID using the **router-id** router subcommand.

Beyond that one small issue, the OSPFv3 configuration is relatively simple. The following list summarizes the configuration steps and commands for later reference and study, with examples to follow:

Key Topic

Step 1. Create an OSPFv3 process number, and enter OSPF configuration mode for that process, using the **ipv6 router ospf** *process-id* global command.

Step 2. Ensure the router has an OSPF router ID, through either:

- **A.** Configuring the **router-id** *id-value* router subcommand
- **B.** Preconfiguring an IPv4 address on any loopback interface whose line status is up
- **C.** Preconfiguring an IPv4 address on any working interface whose line status is up

Step 3. Configure the **ipv6 ospf** *process-id* **area** *area-number* command on each interface on which OSPFv3 should be enabled, to both enable OSPFv3 on the interface and set the area number for the interface.

OSPFv3 Single-Area Configuration Example

Figure 29-7 shows the details of an internetwork used for an OSPFv3 configuration example. The figure shows a single area (area 0). Also, note that Routers R2 and R3 connect to the same VLAN and IPv6 prefix on the right.

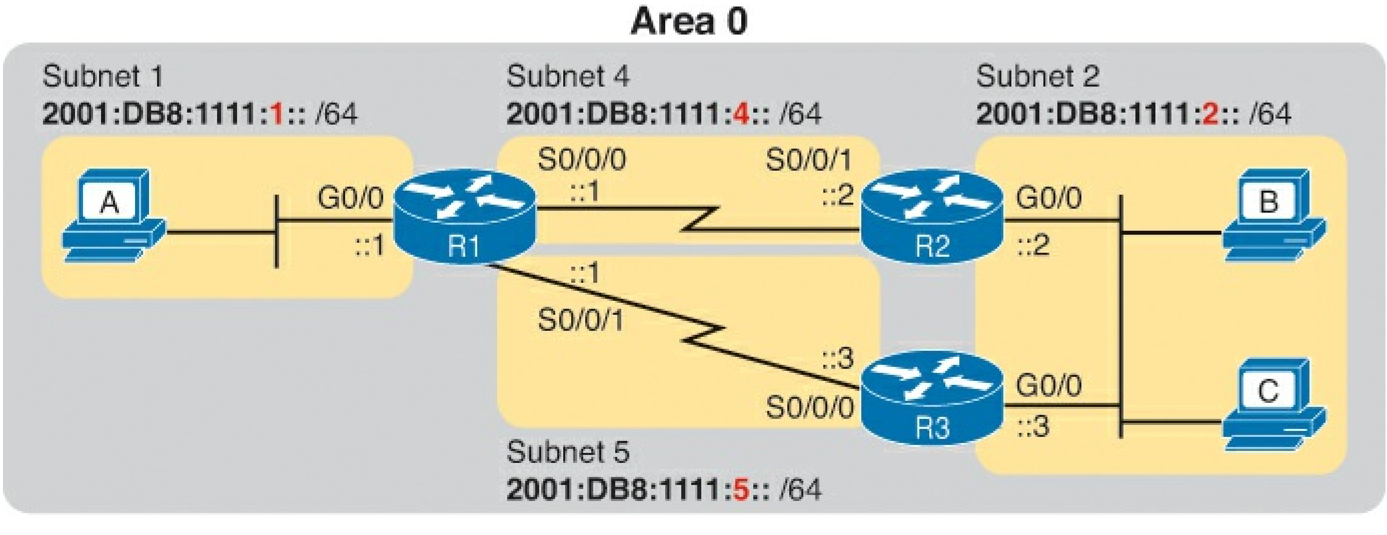


Figure 29-7. Single-Area Design in OSPFv3 Configuration Example

The upcoming OSPFv3 configuration example uses the following requirements:

- All interfaces will be in area 0, so all the **ipv6 ospf** *process-id* **area** *area-number* commands will refer to area 0.
- Each router uses a different OSPF process ID number, just to emphasize the point that the process IDs do not have to match on neighboring OSPFv3 routers.
- Each router sets its router ID directly with the **router-id** command to an obvious number (1.1.1.1, 2.2.2.2, and 3.3.3.3, for R1, R2, and R3, respectively).
- The routers do not use IPv4.

To begin, Example 29-14 shows an excerpt from R1's **show running-config** command before adding the OSPFv3 configuration with the **ipv6 unicast-routing** command, plus an **ipv6 address** command on each interface.

Example 29-14. R1 IPv6 Configuration Reference (Before Adding OSPFv3 Configuration)

```
ipv6 unicast-routing
!
interface serial0/0/0
no ip address
ipv6 address 2001:db8:1111:4::1/64
!
interface serial0/0/1
no ip address
ipv6 address 2001:db8:1111:5::1/64
!
interface GigabitEthernet0/0
no ip address
ipv6 address 2001:db8:1111:1::1/64
```

Example 29-15 begins to show the OSPFv3 configuration, starting on Router R1. Note that at this point, Router R1 has no IPv4 addresses configured, so R1 cannot possibly choose an OSPFv3 RID; it must rely on the configuration of the **router-id** command. Following the example in sequence, the following occurs:

Step 1. The engineer adds the **ipv6 router ospf 1** global command, creating the OSPFv3 process.

Step 2. The router tries to allocate an OSPFv3 RID and fails, so it issues an error message.

Step 3. The engineer adds the **router-id 1.1.1.1** to give R1's OSPFv3 process an RID.

Step 4. The engineer adds **ipv6 ospf 1 area 0** commands to all three interfaces.

Example 29-15. Additional Configuration on R1 to Enable OSPFv3 on Three Interfaces

Click here to view code image

```
R1# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R1(config)# ipv6 router ospf 1
Jan 4 21:03:50.622: %OSPFv3-4-NORTRID: OSPFv3 process 1 could not pick a router-id,
please configure manually
R1(config-rtr)# router-id 1.1.1.1
R1(config-rtr)#
R1(config-rtr)# interface serial0/0/0
R1(config-if)# ipv6 ospf 1 area 0
R1(config-if)# interface serial0/0/1
R1(config-if)# ipv6 ospf 1 area 0
R1(config-if)# interface GigabitEthernet0/0
R1(config-if)# ipv6 ospf 1 area 0
R1(config-if)# end
R1#
```

When looking at the configuration on a single OSPFv3 router, only two other types of parameters can be an issue: the OSPF process ID and the area number. When checking an OSPFv3 configuration for errors, first check the process ID numbers, and make sure that all the values match on that router. For example, the **ipv6 router ospf** *process-id* command's process ID should match all the **ipv6 ospf** *process-id . . .* interface subcommands. The other value, the area number, simply needs to match the planning diagram that shows which interfaces should be in which area.

When comparing two neighboring routers, some parameters must match, or the routers will not become neighbors. Troubleshooting these kinds of problems sits within the scope of the 200-101 ICND2 exam, not the 100-101 ICND1 exam. However, the one big difference between OSPFv2 and OSPFv3 in this neighbor checklist is that OSPFv3 neighbors do not have to have IPv6 prefixes (subnets) or prefix lengths that match. Otherwise, OSPFv3 neighbors must match with items such as both routers being in the same area, having the same Hello interval and the same dead interval.

Example 29-16 shows a completed configuration for Router R2. In this case, Router R2 uses a different OSPF process ID than R1; the process IDs on neighbors do not have to match with OSPFv2 or OSPFv3. R2 creates its OSPFv3 process (2), sets its RID (2.2.2.2), and enables OSPFv3 on all three of its interfaces with the **ipv6 ospf 2 area 0** interface subcommand.

Example 29-16. Complete IPv6 Configuration, Using OSPFv3, on Router R2

```
ipv6 unicast-routing
!
ipv6 router ospf 2
router-id 2.2.2.2
!
interface serial0/0/1
ipv6 address 2001:db8:1111:4::2
```

```
ipv6 ospf 2 area 0
!
interface GigabitEthernet0/0
ipv6 address 2001:db8:1111:2::2
ipv6 ospf 2 area 0
```

OSPFv3 Passive Interfaces

Like OSPFv2, OSPFv3 can be configured to make interfaces passive. Some IPv6 subnets have only one router connected to the subnet. In those cases, the router needs to enable OSPFv3 on the interface, so that the router advertises about the connected subnet, but the router does not need to attempt to discover OSPFv3 neighbors on the interface. In those cases, the engineer can configure the interface as on OSPFv3 passive interface, telling the router to do the following:

- Quit sending OSPF Hellos on the interface
- Ignore received Hellos on the interface
- Do not form neighbor relationships over the interface
- Continue to advertise about any subnets connected to the interface

Interestingly, passive interface configuration works the same for both OSPFv2 and OSPFv3. For example, in the configuration example based on Figure 29-7, only R1 connects to the LAN subnet on the left side of the figure, so R1's G0/0 interface could be made passive to OSPFv3. To do so, the engineer could add the **passive-interface gigabitethernet0/0** subcommand in OSPFv3 configuration mode on Router R1.

For a more complete discussion of how to configure passive interfaces for OSPF, refer to Chapter 17's section "OSPF Passive Interfaces.".

Verifying OSPFv3 Status and Routes

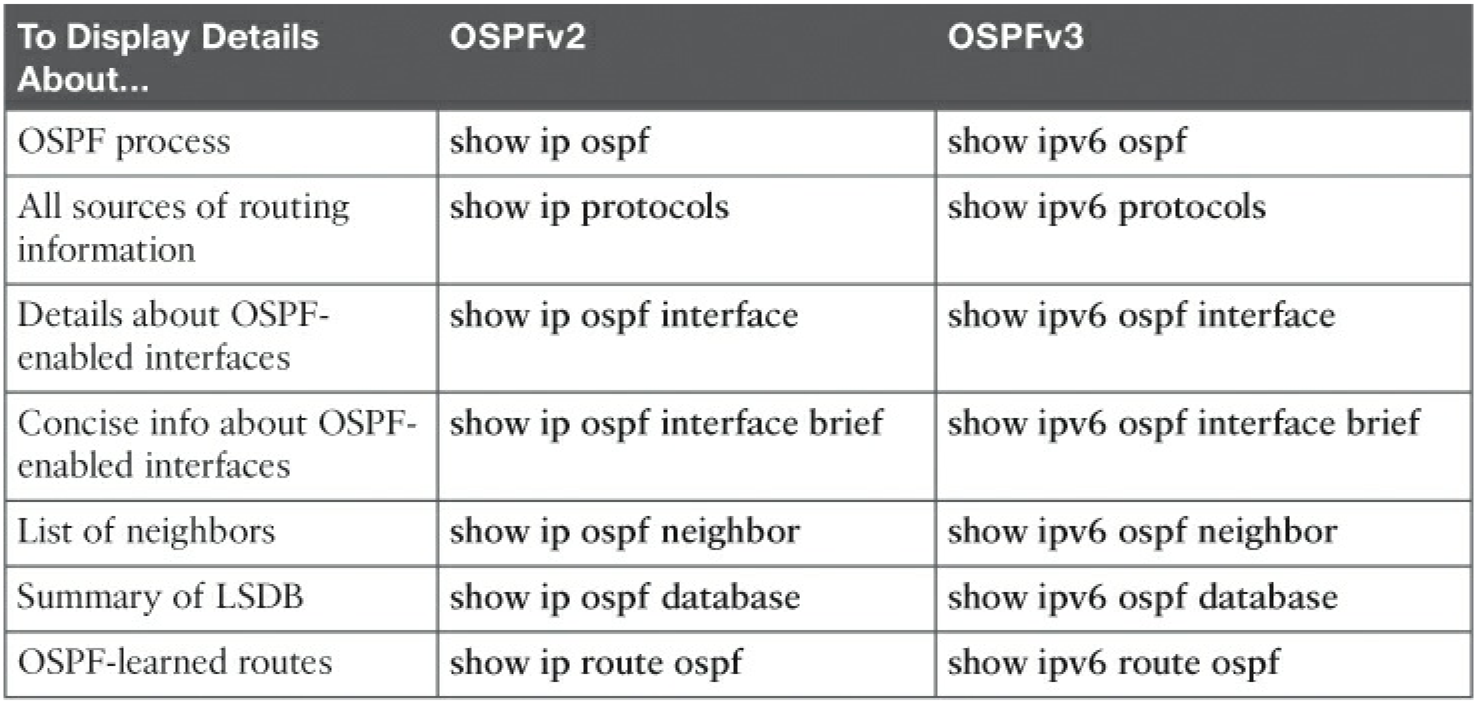
To verify whether OSPFv3 works, you can take two different approaches. You can start at the end, looking at the IPv6 routes added by OSPFv3. If the correct routes show up in the correct routers' routing tables, OSPFv3 must be working correctly. Alternately, you can proceed in the same order that OSPF uses to build the routes: First confirm the configuration settings, then look at the OSPF neighbors, then the OSPF database, and finally look at the routes OSPF added to the routing tables.

When speed matters, look at the routing table first. However, for the sake of learning, it helps to walk through the steps from start to finish, working through a variety of OSPFv3 **show** commands. The rest of this section works through several OSPFv3 **show** commands, in this order:

- Verifying the configuration settings (OSPFv3 process and interfaces)
- Verifying OSPFv3 neighbors
- Verifying the OSPFv3 link-state database (LSDB) and LSAs
- Verifying OSPFv3 routes

This section happens to mention a wide variety of OSPFv3 **show** commands that have a matching and similar OSPFv2 **show** command. Table 29-3 lists these **show** commands for easier reference and study.

Table 29-3. OSPFv2 and Matching OSPFv3 show **Commands**



To Display Details About...	OSPFv2	OSPFv3
OSPF process	show ip ospf	show ipv6 ospf
All sources of routing information	show ip protocols	show ipv6 protocols
Details about OSPF-enabled interfaces	show ip ospf interface	show ipv6 ospf interface
Concise info about OSPF-enabled interfaces	show ip ospf interface brief	show ipv6 ospf interface brief
List of neighbors	show ip ospf neighbor	show ipv6 ospf neighbor
Summary of LSDB	show ip ospf database	show ipv6 ospf database
OSPF-learned routes	show ip route ospf	show ipv6 route ospf

Note

Note that all the OSPFv3 commands use the exact same commands as those for IPv4, except they use **ipv6** instead of the **ip** parameter.

Verifying OSPFv3 Configuration Settings

To verify the OSPFv3 configuration on a router, a simple **show running-config** command works well. However, in some cases in real life, and on the exams with many Simlet questions, you might not be allowed to enter enable mode to use commands like **show running-config**. In those cases, you can re-create the OSPFv3 configuration using several show commands.

To start re-creating the OSPFv3 configuration, look at the output of the **show ipv6 ospf** command. This command lists information about the OSPFv3 process itself. In fact, the first line of output, highlighted in Example 29-17, tells you the following facts about the configuration:

- The router has been configured with OSPFv3 process ID 1, meaning the **ipv6 router ospf 1** command is configured.
- The router uses router ID 1.1.1.1, which means either the **router-id 1.1.1.1** command is configured or the **ip address 1.1.1.1** *mask* command is configured on some interface on the router.

Example 29-17. Verifying OSPFv3 Process Configuration

Click here to view code image

```
R1# show ipv6 ospf
Routing Process "ospfv3 1" with ID 1.1.1.1
Event-log enabled, Maximum number of events: 1000, Mode: cyclic
Initial SPF schedule delay 5000 msecs
Minimum hold time between two consecutive SPFs 10000 msecs
Maximum wait time between two consecutive SPFs 10000 msecs
Minimum LSA interval 5 secs
Minimum LSA arrival 1000 msecs
LSA group pacing timer 240 secs
Interface flood pacing timer 33 msecs
Retransmission pacing timer 66 msecs
Number of external LSA 0. Checksum Sum 0x000000
Number of areas in this router is 1. 1 normal 0 stub 0 nssa
Graceful restart helper support enabled
Reference bandwidth unit is 100 mbps
Area BACKBONE(0)
Number of interfaces in this area is 3
SPF algorithm executed 4 times
Number of LSA 13. Checksum Sum 0x074B38
Number of DCbitless LSA 0
Number of indication LSA 0
Number of DoNotAge LSA 0
Flood list length 0
```

The highlights toward the end of Example 29-17 give some hints about the rest of the configuration, but not enough detail to list every part of the remaining OSPFv3 configuration. The highlighted lines mention three interfaces are in "this area" and that the area is backbone area 0. All these message sit under the heading line at the top of the example, for OSPFv3 process "1." These facts together tell us that this router (R1) uses the following configuration:

- Interface subcommand **ipv6 ospf 1 area 0**.
- The router uses this interface subcommand on three interfaces.

However, the **show ipv6 ospf** command does not identify the interfaces on which OSPFv3 is working. To find those interfaces, use either of the two commands in Example 29-18. Focusing first on the **show ipv6 ospf interface brief** command, this command lists one line for each interface on which OSPFv3 is enabled. Each line lists the interface, the OSPFv3 process ID (under the heading "PID"), the area assigned to the interface, and the number of OSPFv3 neighbors ("Nbrs" heading) known out that interface.

Example 29-18. Verifying OSPFv3 Interfaces

Click here to view code image

```
R1# show ipv6 ospf interface brief
Interface PID Area Intf ID Cost State Nbrs F/C
Gi0/0 1 0 3 1 DR 0/0
Se0/0/1 1 0 7 64 P2P 1/1
Se0/0/0 1 0 6 64 P2P 1/1

R1# show ipv6 protocols
IPv6 Routing Protocol is "connected"
IPv6 Routing Protocol is "ND"
IPv6 Routing Protocol is "ospf 1"
Interfaces (Area 0):
GigabitEthernet0/0
Serial0/0/1
Serial0/0/0
Redistribution:
None
```

Note

Just as with the **show ip ospf interface brief** command, the **show ipv6 ospf interface brief** command lists both nonpassive and passive OSPFv3 interfaces.

The second half of the output in Example 29-18, listing the **show ipv6 protocols** command, lists information about every source of IPv6 routes on the router. This command lists noticeably less detail about OSPFv3 than the **show ip protocol** command lists about OSPFv2. However, both commands list the interfaces on which OSPFv3 is enabled.

Both of the commands in Example 29-18 give enough information to predict that this router (R1) has an **ipv6 ospf 1 area 0** subcommand under three interfaces: G0/0, S0/0/0, and S0/0/1.

Verifying OSPFv3 Neighbors

Verifying OSPFv3 neighbors requires a brief look at a single command: **show ipv6 ospf neighbor**. This command lists one line per neighbor, listing key facts about that neighbor. In particular, it lists the neighbor's RID, the local router's interface through which that neighbor is reached, and the status of the neighbor relationship.

In the OSPFv3 example used in this chapter, each router should have two neighbor relationships. R1 has two serial links, one each to Routers R2 and R3, so R1 will form a neighbor relationship with each of these routers. R2 and R3 both connect to the same IPv6 subnet over a LAN, and will form a neighbor relationship over that LAN. Figure 29-8 shows the expected OSPFv3 neighbor relationships.

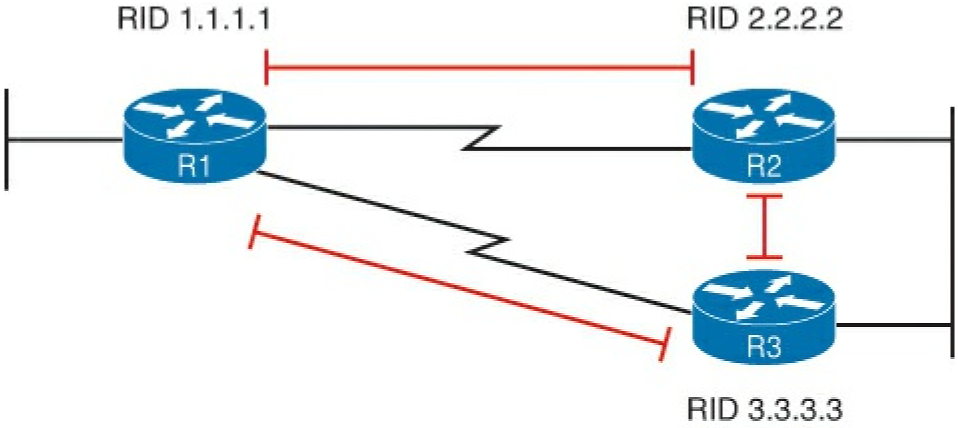


Figure 29-8. Expected OSPFv3 Neighbor Relationships Compared to Figure 29-7

Example 29-19 shows the OSPFv3 neighbor relationships on Routers R1 and R2. The highlighted portions point out the basics, with the neighboring routers' RIDs, local interface, and state. The "FULL" state means that the neighbor relationship is working, and that the neighbors have "fully" completed the exchange of LSAs.

Example 29-19. Verifying OSPFv3 Neighbors on Routers R1 and R2

Click here to view code image

```
! The first command is from router R1, listing R2 and R3
R1# show ipv6 ospf neighbor

Neighbor ID Pri State Dead Time Interface ID Interface
3.3.3.3 0 FULL/ - 00:00:39 6 Serial0/0/1
2.2.2.2 0 FULL/ - 00:00:31 7 Serial0/0/0
```

```
! The next command is from router R2, listing R1 and R3
R2# show ipv6 ospf neighbor

Neighbor ID Pri State Dead Time Interface ID Interface
1.1.1.1 0 FULL/ - 00:00:39 6 Serial0/0/1
3.3.3.3 1 FULL/DR 00:00:33 3 GigabitEthernet0/0
```

Before speeding along to the next topic, take a moment to look again at the output in Example 29-19. Do you see anything in the output that makes you think of IPv6 instead of IPv4? OSPFv3 uses 32-bit RIDs, listed in dotted-decimal notation, so the output looks literally just like the output from the **show ip ospf neighbor** command. The only difference is the command itself, with the **ipv6** keyword.

Examining the OSPFv3 Database

OSPFv3 does differ from OSPFv2 with the theory and details of OSPF LSAs. However, this book mostly ignores LSA details, with the ICND2 book discussing LSAs in a small amount of detail. To understand the differences between OSPFv2 and OSPFv3, the discussion would need to be much deeper.

However, an easy way to do a basic check of the LSDB is to check for Type 1 router LSAs. Both OSPFv2 and OSPFv3 use a Type 1 LSA for every router, with the LSA describing the router itself. The LSA has an identifier equal to the RID of that router. Inside an area, the LSDB should contain one Type 1 LSA for every router in the area. Example 29-20 shows the first section of output from the **show ipv6 ospf database** command and tells you whether a router has learned the Type 1 Router LSA from all the routers.

Example 29-20. Verifying OSPFv3 LSDB on R1

Click here to view code image

```
R2# show ipv6 ospf database

OSPFv3 Router with ID (2.2.2.2) (Process ID 2)

Router Link States (Area 0)

ADV Router Age Seq# Fragment ID Link count Bits
```

```
1.1.1.1 452 0x80000002 0 2 None
2.2.2.2 456 0x80000004 0 2 None
3.3.3.3 457 0x80000005 0 2 None

! Lines omitted for brevity
```

The example shows three lines of data under the heading lines in the section titled “Router Link States.” This section shows data about the Type 1 Router LSAs. In that section, the heading “ADV Router” referring to the router that advertised the LSA. In this case, R1 (RID 1.1.1.1) knows its own Type 1 LSA, plus R2’s (RID 2.2.2.2) and R3’s (RID 3.3.3.3).

Examining IPv6 Routes Learned by OSPFv3

Finally, the real proof of whether OSPFv3 works is whether the routers learn and add any IPv6 routes to the IPv6 routing table. This section completes the verification process with a look at the IPv6 routes added by OSPFv3.

When working correctly, OSPFv3 routers learn enough information to create routes for all IPv6 prefixes (subnets) in the internetwork. The one big difference as compared with OSPFv2 is that OSPFv3-learned routes use a link-local next-hop address. For example, in the internetwork shown in Figure 29-9, which is the same design used for the OSPFv3 configuration example, R2 adds a route to subnet 1 on the left (subnet 2001:DB8:1111:1::/64). R2 uses R1’s link-local address as the next-hop address, as shown in the figure.

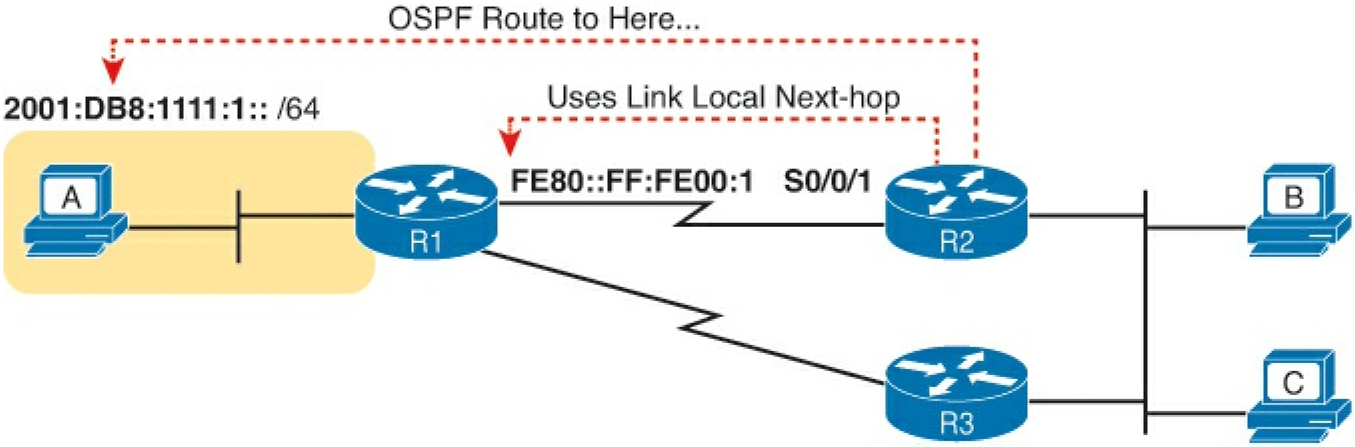


Figure 29-9. OSPFv3 and Its Use of Link-Local Addresses

Example 29-21 lists the output from the **show ipv6 route ospf** command on Router R2, for the route highlighted in Figure 29-9. Of particular importance, note

- Code letter “O” meaning “OSPF”
- In brackets, 110, the administrative distance of OSPF, and 65, the metric for this route
- The fact that the route lists both the link-local address and the outgoing interface

Example 29-21. OSPFv3 Routes on Router R2

Click here to view code image

```
R2# show ipv6 route ospf
IPv6 Routing Table - default - 9 entries
! Legend omitted for brevity

O 2001:DB8:1111:1::/64 [110/65]
via FE80::FF:FE00:1, Serial0/0/1
O 2001:DB8:1111:5::/64 [110/65]
via FE80::FF:FE00:3, GigabitEthernet0/0
```

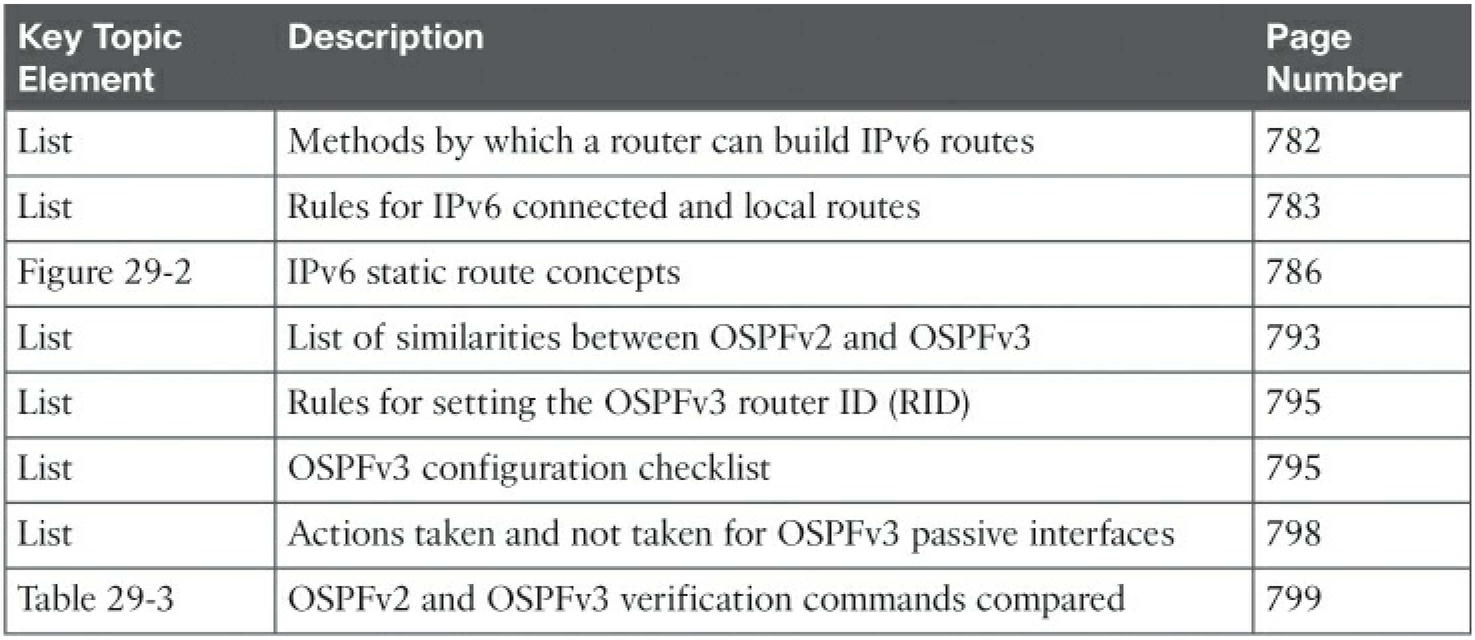
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 29-4 lists these key topics and where each is discussed.

Key Topic

Table 29-4. Key Topics for Chapter 29



Key Topic Element	Description	Page Number
List	Methods by which a router can build IPv6 routes	782
List	Rules for IPv6 connected and local routes	783
Figure 29-2	IPv6 static route concepts	786
List	List of similarities between OSPFv2 and OSPFv3	793
List	Rules for setting the OSPFv3 router ID (RID)	795
List	OSPFv3 configuration checklist	795
List	Actions taken and not taken for OSPFv3 passive interfaces	798
Table 29-3	OSPFv2 and OSPFv3 verification commands compared	799

Complete the Tables and Lists from Memory

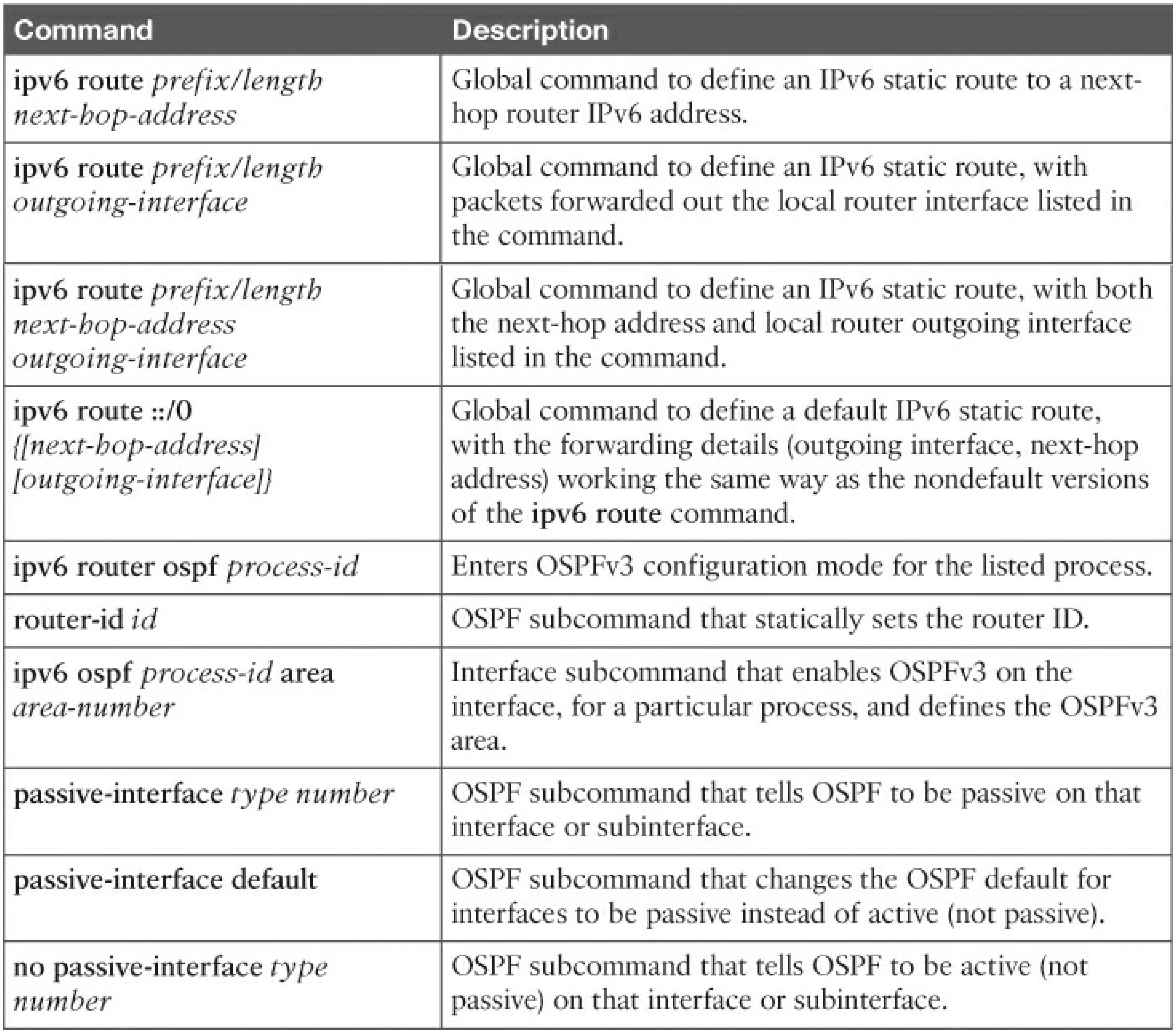
Print a copy of DVD Appendix M, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix N, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Definitions of Key Terms

Because this chapter has so many concepts in common with the IPv4-equivalent tools, the only new term is OSPF version 3. Feel free to check your mental definition of OSPFv3 versus the definition in the glossary.

Command Reference to Check Your Memory

Table 29-5. Chapter 29 Configuration Command Reference



Command	Description
ipv6 route *prefix/length next-hop-address*	Global command to define an IPv6 static route to a next-hop router IPv6 address.
ipv6 route *prefix/length outgoing-interface*	Global command to define an IPv6 static route, with packets forwarded out the local router interface listed in the command.
ipv6 route *prefix/length next-hop-address outgoing-interface*	Global command to define an IPv6 static route, with both the next-hop address and local router outgoing interface listed in the command.
ipv6 route ::/0 *{[next-hop-address] [outgoing-interface]}*	Global command to define a default IPv6 static route, with the forwarding details (outgoing interface, next-hop address) working the same way as the nondefault versions of the **ipv6 route** command.
ipv6 router ospf *process-id*	Enters OSPFv3 configuration mode for the listed process.
router-id *id*	OSPF subcommand that statically sets the router ID.
ipv6 ospf *process-id* **area** *area-number*	Interface subcommand that enables OSPFv3 on the interface, for a particular process, and defines the OSPFv3 area.
passive-interface *type number*	OSPF subcommand that tells OSPF to be passive on that interface or subinterface.
passive-interface default	OSPF subcommand that changes the OSPF default for interfaces to be passive instead of active (not passive).
no passive-interface *type number*	OSPF subcommand that tells OSPF to be active (not passive) on that interface or subinterface.

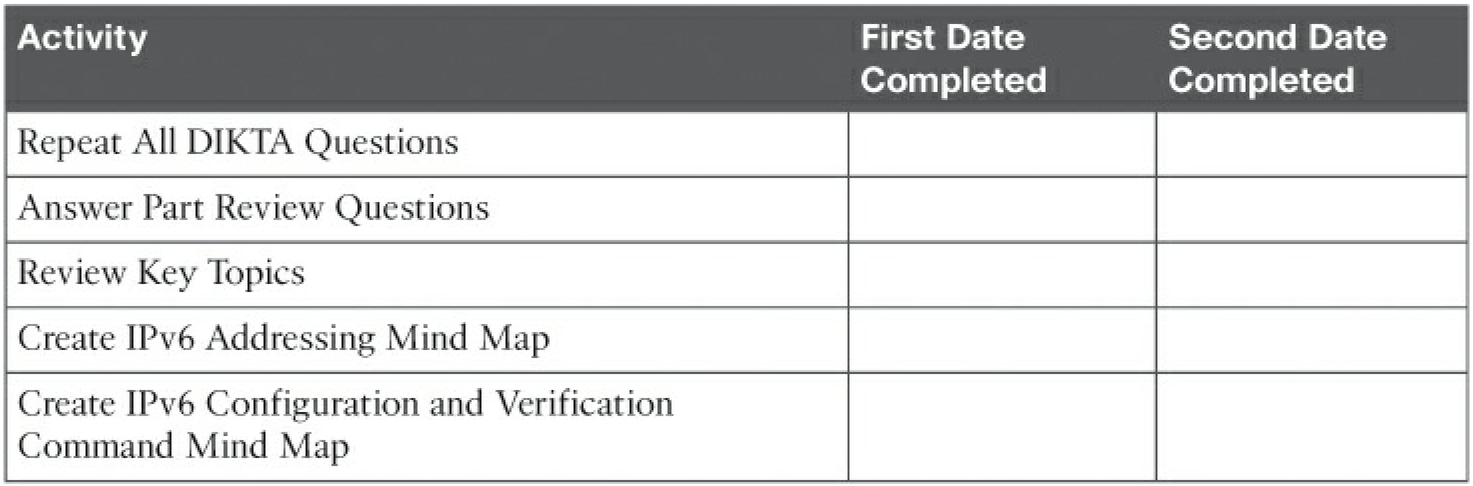
Table 29-6. Chapter 29 EXEC Command Reference

Command	Description
show ipv6 route [**ospf**]	Lists routes in the routing table learned by OSPFv3.
show ipv6 ospf	Shows routing protocol parameters and current timer values for OSPFv3, and the OSPFv3 router ID.
show ipv6 ospf interface brief	Lists one line of output per OSPFv3-enabled interface, with basic settings listed, like OSPFv3 process, area number, and interface cost.
show ip ospf neighbor [*neighbor-RID*]	Lists neighbors and current status with neighbors, per interface, and optionally lists details for the router ID listed in the command.
show ipv6 ospf database	Lists a summary of the LSAs in the local router's LSDB, listing one line for each LSA.
show ipv6 protocols	Lists briefer information than the IPv4 **show ip protocols** command, primarily listing all means through which a router can learn or build IPv6 routes, and interfaces on which a routing protocol is enabled.

Part VII Review

Keep track of your part review progress with the checklist in Table P7-1. Details on each task follow the table.

Table P7-1. Part VII Part Review Checklist



Activity	First Date Completed	Second Date Completed
Repeat All DIKTA Questions		
Answer Part Review Questions		
Review Key Topics		
Create IPv6 Addressing Mind Map		
Create IPv6 Configuration and Verification Command Mind Map		

Repeat All DIKTA Questions

For this task, answer the "Do I Know This Already?" questions again for the chapters in this part of the book, using the PCPT software. Refer to the Introduction to this book, heading "How to View Only DIKTA Questions by Part," for help with how to make the PCPT software show you DIKTA questions for this part only.

Answer Part Review Questions

For this task, answer the Part Review questions for this part of the book, using the PCPT software. Refer to the Introduction to this book, heading "How to View Only Part Review Questions by Part," for help with how to make the PCPT software show you Part Review questions for this part only.

Review Key Topics

Key Topic

Browse back through the chapters, and look for the Key Topics icons. If you do not remember some details, take the time to reread those topics.

Create IPv6 Addressing Mind Map

Addressing is the biggest difference between IPv4 and IPv6. Think about IPv6 addresses for a few moments—the terms, the structure, the types, and anything related to addressing. Then make a mind map that collects all the addressing concepts and terms into one mind map.

When thinking about addressing, try to organize the information to your liking. There is no one right answer. However, if you want some guidance on how to organize the information, some of the concepts and terms can be organized by type of address. For instance, link-local addresses would be one type. In that part of the mind map, you could list all terms and facts about link-local addresses, as shown in Figure P7-1.

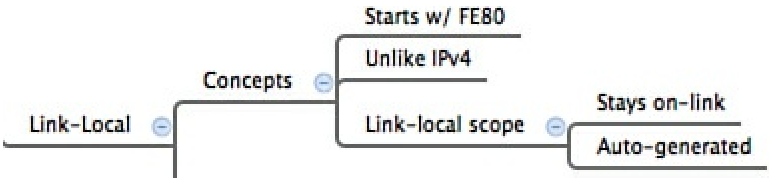


Figure P7-1. Sample Mind Map for the Link-Local Branch

Chapter 25, "Fundamentals of IP Version 6," through Chapter 27, "Implementing IPv6 Addressing on Routers," contain most of the IPv6 addressing concepts in this book. Try to fit all the addressing terms from the Key Terms sections of those chapters into the map, along with all IPv6 addressing concepts and the values that identify an address as being a particular type of IPv6 address.

Create IPv6 Configuration and Verification Command Mind Map

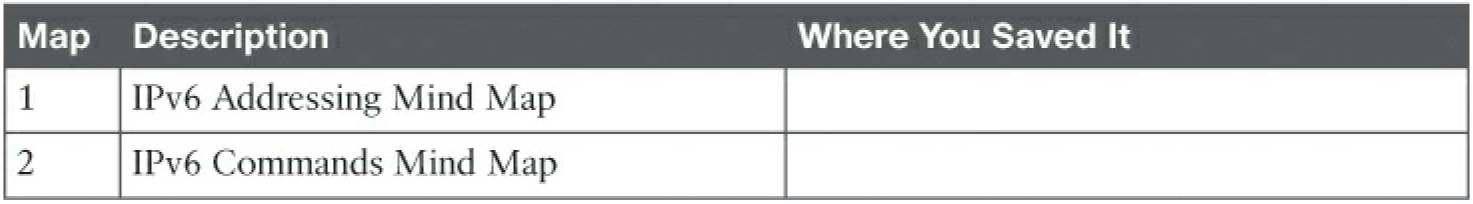
Without referring to your notes or the book, create a mind map of all the IPv6 router commands you can recall. The goal with this mind map exercise is to help you remember the commands, but not necessarily every last parameter. The goal is to help you organize the commands internally so that you know which commands to consider when faced with a real-life problem or an exam question.

Organize your commands first by a major topic. Then, for a given topic, separate the commands based on configuration versus verification command. Some suggested major topics:

addresses, static routes, OSPFv3

Appendix O, "Mind Map Solutions," lists sample mind map answers, but as usual, your mind map can and will look different.

Table P7-2. Configuration Mind Maps for Part VII Review



Map	Description	Where You Saved It
1	IPv6 Addressing Mind Map	
2	IPv6 Commands Mind Map	

Part VIII: Final Review

Chapter 30: Final Review

Chapter 30. Final Review

Congratulations! You made it through the book, and now it's time to finish getting ready for the exam. This chapter helps you get ready to take and pass the exam in three ways.

This chapter begins by talking about the exam itself. You know the content and topics. Now you need to think about what happens during the exam, and what you need to do in these last few weeks before taking the exam. At this point, everything you do should be focused on getting you ready to pass so that you can finish up this hefty task.

The second section of this chapter gives you some exam review tasks as your final preparation for your ICND1, ICND2, or CCNA exam.

Advice About the Exam Event

Now that you have finished the bulk of this book, you could just register for your Cisco ICND1, ICND2, or CCNA exam; show up; and take the exam. However, if you spend a little time thinking about the exam event itself, learning more about the user interface of the real Cisco exams, and the environment at the Vue testing centers, you will be better prepared, particularly if this is your first Cisco exam. This first of three major sections in this chapter gives some advice about the Cisco exams and the exam event itself.

Learn the Question Types Using the Cisco Certification Exam Tutorial

In the weeks leading up to your exam, you should think more about the different types of exam questions and have a plan for how to approach those questions. One of the best ways to learn about the exam questions is to use the Cisco Exam Tutorial.

To find the Cisco Certification Exam Tutorial, go to www.cisco.com and search for "exam tutorial." The tutorial sits inside a web page with a Flash presentation of the exam user interface. The tutorial even lets you take control as if you were taking the exam. When using the tutorial, make sure that you take control and try the following:

- Try to click next on the multichoice, single-answer question without clicking an answer, and see that the testing software tells you that you have too few answers.
- On the multichoice, multianswer question, select too few answers and click Next to again see how the user interface responds.
- In the drag-and-drop question, drag the answers to the obvious answer locations, but them drag them back to the original location. (You might do this on the real exam, if you change your mind when answering the question.)
- On the Simulation question, first just make sure that you can get to the command-line interface (CLI) on one of the routers. To do so, you have to click the PC icon for a PC connected to the router console; the console cable appears as a dashed line, while network cables are solid lines.
- Still on the Sim question, make sure that you look at the scroll areas at the top, at the side, and in the terminal emulator window.
- Still on the Sim question, make sure that you can toggle between the topology window and the terminal emulator window by clicking "Show topology" and "Hide topology."
- On the Testlet question, answer one multichoice question, move to the second and answer it, and then move back to the first question, confirming that inside a Testlet, you can move around between questions.
- Again on the Testlet question, click the Next button to see the pop-up window that Cisco uses as a prompt to ask whether you want to move on. Testlets might actually allow you to give too few answers and still move on. After you click to move past the Testlet, you cannot go back to change your answer for any of these questions.

Think About Your Time Budget Versus Numbers of Questions

On exam day, you need to keep an eye on your speed. Going too slowly hurts you because you might not have time to answer all the questions. Going too fast can be hurtful, if your fast speed is because you are rushing and not taking the time to fully understand the questions. So, you need to be able to somehow know whether you are moving quickly enough to answer all the questions, while not rushing.

The exam user interface shows some useful information, namely a countdown timer as well as question counter. The question counter shows a question number for the question you are answering, and it shows the total number of questions on your exam.

Unfortunately, treating each question as equal does not give you an accurate time estimate. For example, if your exam allows 90 minutes, and your exam has 45 questions, you would have two minutes per question. After answering 20 questions, if you had taken 40 minutes, you would be right on time. However, several factors make that kind of estimate difficult.

First, Cisco does not tell us beforehand the exact number of questions for each exam. For example, the Cisco website might list the CCNA exam as having from 45 to 55 questions. (The ICND1 and ICND2 exams have similar ranges.) But you do not know how many questions are on your exam until it begins, when you go through the screens that lead up to the point where you click "Start exam."

Next, some questions (call them *time burners*) clearly take a lot more time to answer:

Normal-time questions: Multichoice and drag-and-drop, approximately 1 minute each

Time burners: Sims, Simlets, and Testlets, approximately 6–8 minutes each

Finally, in the count of 45–55 questions on a single exam, even though Testlet and Simlet questions contain several multichoice questions, the exam software counts each Testlet and Simlet question as one question in the question counter. For example, if a Testlet question has four embedded multiple-choice questions, in the exam software's question counter, that counts as one question.

Note

While Cisco does not tell us why you might get 45 questions, while someone else taking the same exam might get 55 questions, it seems reasonable to think that the person with 45 questions might have a few more of the time burners, making the two exams equivalent.

You need a plan for how you will check your time, a plan that does not distract you from the exam. It might be worth taking a bit of a guess, to keep things simple, like this:

> 50 questions, 90 minutes, is a little less than two minutes per question, and just guess a little based on how many time-burner questions you have seen so far.

No matter how you plan to check your time, think about it before exam day. You can even use the method listed under the next heading.

A Suggested Time-Check Method

The following math can be used to do your time check in a way that weights the time based on those time-burner questions. You do not have to use this method. But this math uses only addition of whole numbers, to keep it simple. It gives you a pretty close time estimate, in my opinion.

The concept is simple. Just do a simple calculation that estimates the time you should have used so far. Here's the math:

> Number of Questions Answered So Far + 7 Per Time Burner

Then, you check the timer to figure out how much time you have spent:

- You have used exactly that much time, or a little more: Your timing is perfect.
- You have used less time: You are ahead of schedule.
- You have used noticeably more time: You are behind schedule.

For example, if you have already finished 17 questions, 2 of which were time burners, your time estimate is 17 + 7 + 7 = 31 minutes. If your actual time is also 31 minutes, or maybe 32 or 33 minutes, you are right on schedule. If you have spent less than 31 minutes, you are ahead of schedule.

So, the math is pretty easy: Questions answered, plus 7 per time burner, is the guesstimate of how long you should take if you are right on time.

Note

This math is an estimate; I make no guarantees that the math will be an accurate predictor on every exam.

Miscellaneous Pre-Exam Suggestions

Here are just a few more suggestions for things to think about before exam day arrives:

- Get some earplugs. Testing centers often have some, but if you do not want to chance it, come prepared. The testing center is typically a room inside the space of a company that does something else as well, oftentimes a training center. So, there are people talking in nearby rooms and others office noises. Earplugs can help. (Headphones, as electronic devices, would not be allowed.)
- Some people like to spend the first minute of the exam writing down some notes for reference. For example, maybe you want to write down the table of magic numbers for finding IPv4 subnet IDs. If you plan to do that, practice making those notes. Before each practice exam, transcribe those lists, just like you expect to do at the real exam.
- Plan your travel to the testing center with enough time so that you will not be rushing to make it just in time.
- If you tend to be nervous before exams, practice your favorite relaxation techniques for a few minutes before each practice exam, just to be ready to use them.

Exam-Day Advice

I hope the exam goes well for you. Certainly, the better prepared you are, the better chances you have on the exam. But these small tips can help you do your best on exam day:

- Rest the night before the exam, rather than staying up late to study. Clarity of thought is more important than one extra fact, especially because the exam requires so much analysis and thinking rather than just remembering facts.
- If you did not bring earplugs, ask the testing center for some, even if you cannot imagine you would use them. You never know whether it might help.
- You can bring personal effects into the building and testing company's space, but not into the actual room in which you take the exam. So, take as little extra stuff with you as possible. If you have a safe place to leave briefcases, purses, electronics, and so on, leave them there. However, the testing center should have a place to store your things as well.

Simply put, the less you bring, the less you have to worry about storing. (For example, I have even been asked to remove even my analog wristwatch on more than one occasion.)

- The exam center will give you a laminated sheet and pen, as a place to take notes. (Test center personnel typically do not let you bring paper and pen into the room, even if supplied by the testing center.)
- Leave for the testing center with extra time, so you do not have to rush.
- Plan on finding a restroom before going into the testing center. If you cannot find one, of course you can use one in the testing center, and test personnel will direct you and give you time before your exam starts.
- Do not drink a 64-ounce drink on the trip to the testing center. After the exam starts, the exam timer will not stop while you go to the restroom.
- On exam day, use any relaxation techniques that you have practiced to help get your mind focused while you wait for the exam.

Exam Review

This exam review completes the Study Plan materials as suggested by this book. At this point, you have read the other chapters of the book, and you have done the chapter review Exam Preparation Tasks and Part Review tasks. Now you need to do the final study and review activities before taking the exam, as detailed in this section.

The Exam Review section suggests some new activities, as well as repeating some old. However, whether new or old, the activities all focus on filling in your knowledge gaps, finishing off your skills, and completing the study process. While repeating some tasks you did at chapter review and part review can help, you need to be ready to take an exam, so the exam review asks you to spend a lot of time answering exam questions.

The exam review walks you through suggestions for several types of tasks, and gives you some tracking tables for each activity. The main categories are

- Practicing for speed
- Taking practice exams
- Finding what you do not know well yet (knowledge gaps)
- Configuring and verifying functions from the CLI
- Repeating the chapter and Part Review tasks

Practice Subnetting and Other Math-Related Skills

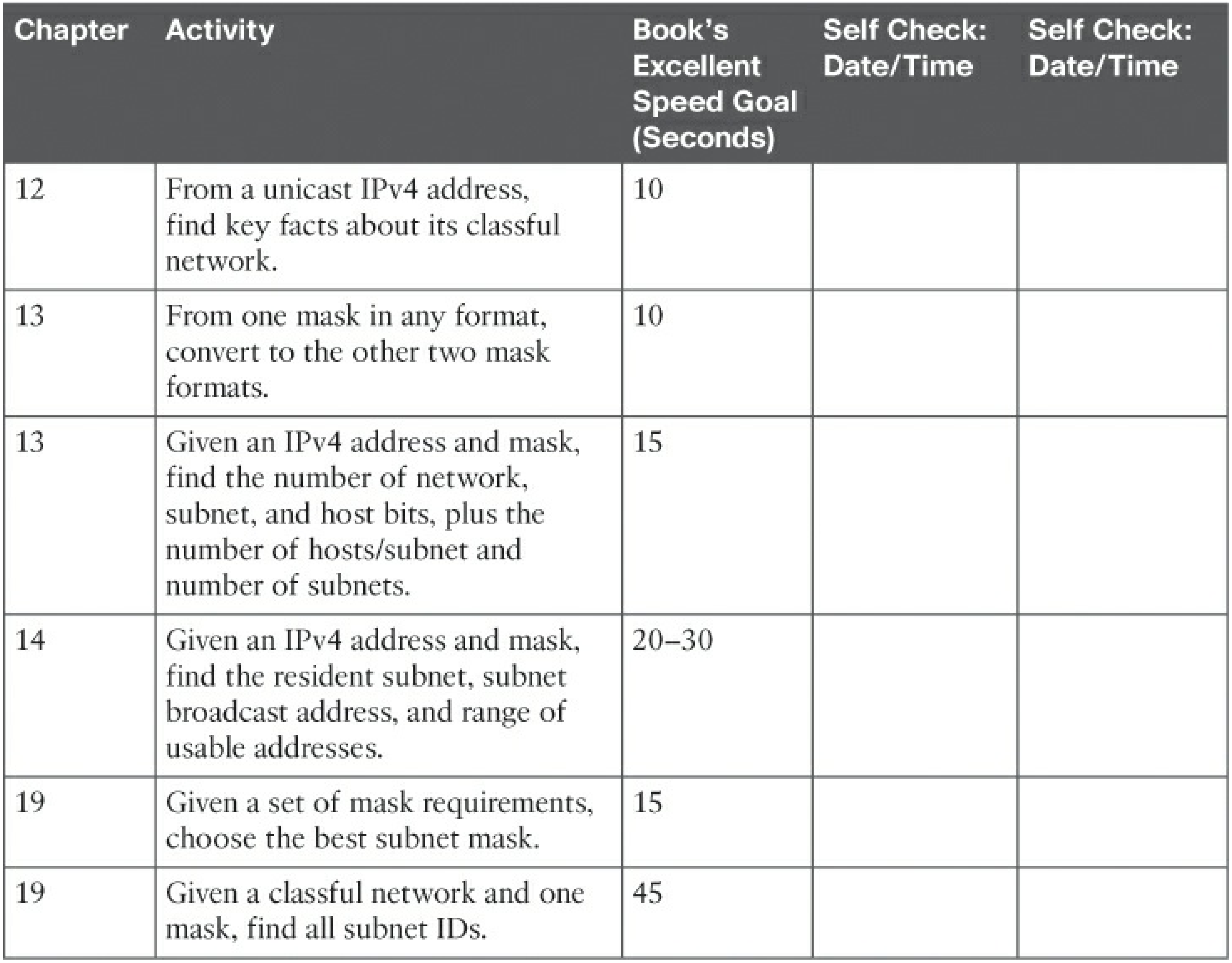
Like it or not, some of the questions on the Cisco ICND1, ICND2, and CCNA exams require you to do some math. To pass, you have to be good at the math. You also need to know when to use each process.

The Cisco exams also have a timer. Some of the math crops up often enough so that, if you go slow with the math, or if you have to write down all the details of how you compute the answers, you might well run out of time to answer all the questions. (The two biggest reasons I hear about why people do not finish on time are these: slow speed with the math-related work and slow speed when doing simulator questions using the CLI.)

However, look at these math processes and the time crunch as a positive instead of a negative. Right now, before the exam, you know about the challenge. You know that if you keep practicing subnetting and other math, you will keep getting faster and better. As exam day approaches, if you have spare minutes, try more practice with anything to do with subnetting in particular. Look at it as a way to prepare now so that you do not have to worry about time pressure so much on the day of the exam.

Table 30-1 lists the topics in this chapter that both require math and require speed. Table 30-2 lists items for which the math or process is important, but speed is probably less important. By this point in your study, you should already be confident at finding the right answer to these kinds of problems. Now is the time to finish off your skills at getting the right answers, plus getting faster so that you reduce your time pressure on the exams.

Table 30-1. ICND1 Math-Related Activities That Benefit from Speed Practice

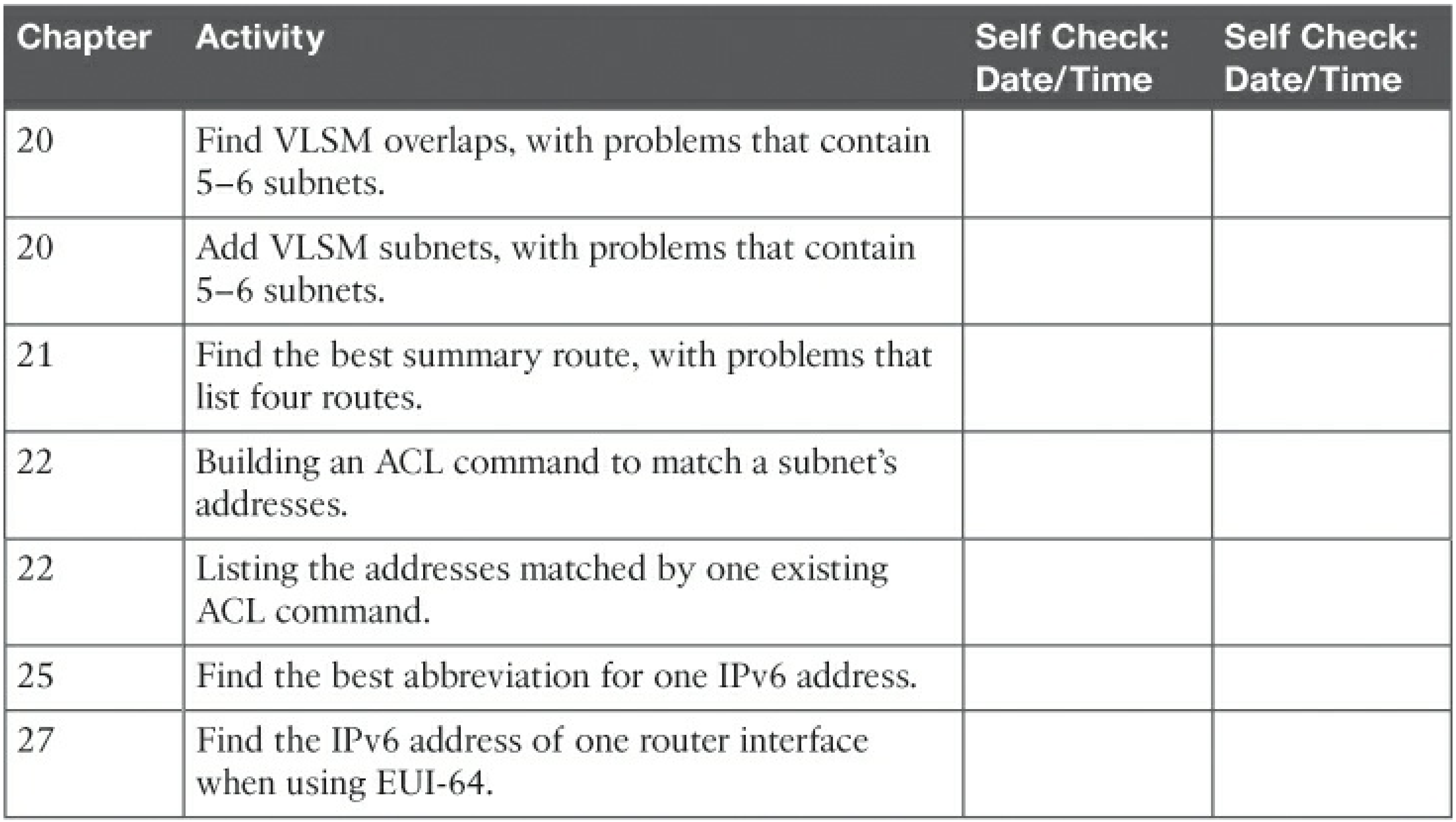


Chapter	Activity	Book's Excellent Speed Goal (Seconds)	Self Check: Date/Time	Self Check: Date/Time
12	From a unicast IPv4 address, find key facts about its classful network.	10		
13	From one mask in any format, convert to the other two mask formats.	10		
13	Given an IPv4 address and mask, find the number of network, subnet, and host bits, plus the number of hosts/subnet and number of subnets.	15		
14	Given an IPv4 address and mask, find the resident subnet, subnet broadcast address, and range of usable addresses.	20–30		
19	Given a set of mask requirements, choose the best subnet mask.	15		
19	Given a classful network and one mask, find all subnet IDs.	45		

Note

The time goals in the table are goals chosen by the author to give you an idea of a good time. If you happen to be a little slower on a few tasks, that does not mean you cannot do well on the test. But if you take several times as much time for almost every task, know that the math-related work can cause you some time problems.

Table 30-2. ICND1 Math-Related Activities That Can Be Less Time Sensitive



Chapter	Activity	Self Check: Date/Time	Self Check: Date/Time
20	Find VLSM overlaps, with problems that contain 5–6 subnets.		
20	Add VLSM subnets, with problems that contain 5–6 subnets.		
21	Find the best summary route, with problems that list four routes.		
22	Building an ACL command to match a subnet's addresses.		
22	Listing the addresses matched by one existing ACL command.		
25	Find the best abbreviation for one IPv6 address.		
27	Find the IPv6 address of one router interface when using EUI-64.		

To practice the math listed in both Tables 30-1 and 30-2, look at the end of the respective chapters for some suggestions. For example, for many subnetting problems, you can make up your own problems and check your work with any subnet calculator. Additionally, all these chapters have matching DVD appendices with additional practice. Finally, the author's blogs include extra practice problems, created just to give you another source from which to practice.

Take Practice Exams

One day soon, you need to pass a real Cisco exam at a Vue testing center. So, it's time to practice the real event as much as possible.

A practice exam using the Pearson IT Certification Practice Test (PCPT) exam software lets you experience many of the same issues as when taking a real Cisco exam. The software gives you a number of questions, with a countdown timer shown in the window. After you answer a question, you cannot go back to it (yes, that's true on Cisco exams). If you run out of time, the questions you did not answer count as incorrect.

The process of taking the timed practice exams helps you prepare in three key ways:

- To practice the exam event itself, including time pressure, the need to read carefully, with a need to concentrate for long periods
- To build your analysis and critical thinking skills when examining the network scenario built into many questions
- To discover the gaps in your networking knowledge so that you can study those topics before the real exam

As much as possible, treat the practice exam events as if you were taking the real Cisco exam at a Vue testing center. The following list gives some advice on how to make your practice exam more meaningful, rather than as just one more thing to do before exam day rolls around:

- Set aside two hours for taking the 90-minute timed practice exam.
- Make a list of what you expect to do for the ten minutes before the real exam event. Then visualize yourself doing those things. Before taking each practice exam, practice those final ten minutes before your exam timer starts. (The earlier section "Exam-Day Advice" lists some suggestions about what to do in those last ten minutes.)
- You cannot bring anything with you into the Vue exam room, so remove all notes and help materials from your work area before taking a practice exam. You can use blank paper, a pen, and your brain only. Do not use calculators, notes, web browsers, or any other app on your computer.
- Real life can get in the way, but if at all possible, ask anyone around you to leave you alone for the time you will practice. If you must do your practice exam in a distracting environment, wear headphones or earplugs to reduce distractions.
- Do not guess, hoping to improve your score. Answer only when you have confidence in the answer. Then, if you get the question wrong, you can go back and think more about the question in a later study session.

Practicing Taking the ICND1 Exam

Because you are reading this chapter in the *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*, you should be preparing for either the ICND1 exam or the CCNA exam. The PCPT exam software, and the exams you get with this ICND1 book, let you take practice exams for both the ICND1 and CCNA exams.

To take an ICND1 practice exam, you need to select one or both of the ICND1 exams from PCPT. If you followed the study plan in this book, you will not have seen any of the questions in these two exam databases before now. After you select one of these two exams, you simply need to choose the Practice Exam option in the upper right and start the exam.

You should plan to take between one and three ICND1 practice exams with these exam databases. Even people who are already well-prepared should do at least one practice exam, just to experience the time pressure and the need for prolonged concentration. For those who want more practice exams, these two exam databases have enough questions for more than two exams. As a result, if you took a fourth practice exam with these exam databases, you will have seen almost all the questions before, making the practice exam a little too easy. If you are interested in purchasing more practice exams, check out the *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide Premium Edition eBook and Practice Test* product at www.ciscopress.com/title/9780133367881 and be sure to use the 70% off coupon included in the DVD sleeve of this book.

Table 30-3 gives you a checklist to record your different practice exam events. Note that recording both the date and the score is helpful for some other work you will do, so note both. Also, in the Time Notes section, if you finish on time, note how much extra time you had; if you run out of time, note how many questions you did not have time to answer.

Table 30-3. ICND1 Practice Exam Checklist

Exam	Date	Score	Time Notes
ICND1			
ICND1			
ICND1			
ICND1			

Practicing Taking the CCNA Exam

If you plan on using the one-exam path to CCNA, and taking the CCNA exam, you should plan on taking CCNA practice exams and avoid the ICND1 and ICND2 practice exams. The CCNA practice exams use the same mix of questions as do the ICND1 and ICND2 practice exams, and it is best to save those questions for your CCNA practice exams.

Both the ICND1 book and the ICND2 book give you the rights to two CCNA exam question banks. If you own only one of those two books, simply use the two exams with "CCNA Full Exam" in the title. If you own both books, you have two sets of two CCNA exam banks, for a total of four unique CCNA exams. Figure 30-1 shows the ideas and the names of the exam in the PCPT software.

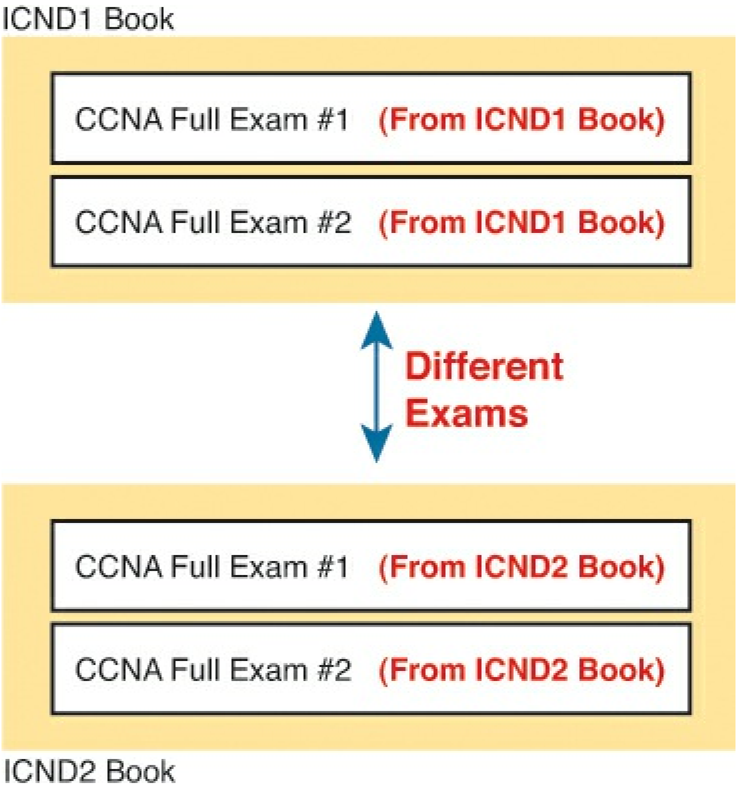

ICND1 Book
CCNA Full Exam #1 (From ICND1 Book)
CCNA Full Exam #2 (From ICND1 Book)
Different Exams
CCNA Full Exam #1 (From ICND2 Book)
CCNA Full Exam #2 (From ICND2 Book)
ICND2 Book

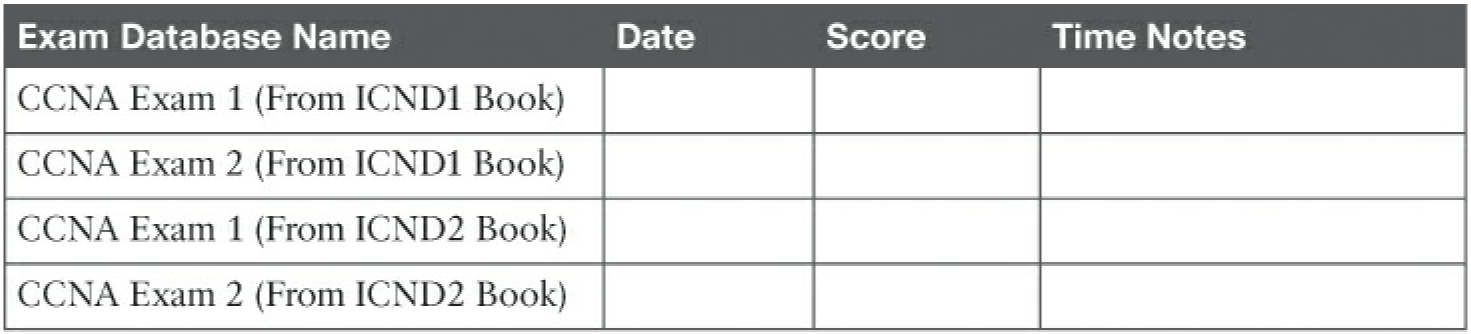
Figure 30-1. CCNA Exam Banks in the ICND1 and ICND2 Books

To take a CCNA exam, select one of the CCNA exam databases from the PCPT window. Then choose the Mode option of

"Practice Exam" and start the exam.

For the CCNA practice exam, you should plan to take at least one practice exam, but you could take up to four practice exams using these exam databases. Table 30-4 gives you a checklist to record your different practice exam events. Note that recording both the date and the score is helpful for some other work you will do, so note both. Also, in the Time Notes section, if you finish on time, note how much extra time you had; if you run out of time, note how many questions you did not have time to answer.

Table 30-4. CCNA Practice Exam Checklist



Exam Database Name	Date	Score	Time Notes
CCNA Exam 1 (From ICND1 Book)			
CCNA Exam 2 (From ICND1 Book)			
CCNA Exam 1 (From ICND2 Book)			
CCNA Exam 2 (From ICND2 Book)			

> **Note**
>
> The PCPT software lists, for the ICND1 book, two exam databases with the name ICND1 and two with the name CCNA. The questions in these two pairs of exam databases overlap, so it makes sense to either take ICND1 practice exams or CCNA practice exams, depending on what test you are preparing for, but not both.

Advice on How to Answer Exam Questions

Open a web browser. Yes, take a break and open a web browser on any device. Do a quick search on a fun topic. Then, before you click a link, get ready to think where your eyes go for the first 5–10 seconds after you click the link. Now, click a link and look at the page. Where did your eyes go?

Interestingly, web browsers, and the content on those web pages, have trained us all to scan. Web page designers actually design content with the expectation that people will scan with different patterns. Regardless of the pattern, when reading a web page, almost no one reads sequentially, and no one reads entire sentences. They scan for the interesting graphics and the big words, and then scan the space around those noticeable items.

Other parts of our electronic culture have also changed how the average person reads. For example, many of you grew up using texting and social media, sifting through hundreds or thousands of messages—but each messages barely fills an entire sentence. (In fact, that previous sentence would not fit in a tweet, being longer than 140 characters.)

Those everyday habits have changed how we all read and think in front of a screen. Unfortunately, those same habits often hurt our scores when taking computer-based exams.

If you scan exam questions like you read web pages, texts, and tweets, you will probably make some mistakes because you missed a key fact in the question, answer, or exhibits. It helps to start at the beginning, and read all the words—a process that is amazingly unnatural for many people today.

> **Note**
>
> I have talked to many college professors, in multiple disciplines, and Cisco Networking Academy instructors, and they consistently tell me that the number-one test-taking issue today is that people do not read the question well enough to understand the details.

When taking the practice exams, and answering individual questions, let me make two suggestions. First, before the practice exam, think about your own personal strategy for how you will read a question. Make your approach to multiple-choice questions in particular be a conscious decision on your part. Second, if you want some suggestions on how to read an exam question, use the following strategy:

Step 1. Read the question itself, thoroughly, from start to finish.

Step 2. Scan any exhibit (usually command output) or figure.

Step 3. Scan the answers to look for the types of information. (Numeric? Terms? Single words? Phrases?)

Step 4. Reread the question thoroughly, from start to finish, to make sure that you understand it.

Step 5. Read each answer thoroughly, while referring to the figure/exhibit as needed. After reading each answer, before reading the next answer:

- **A.** If correct, select as correct.
- **B.** If for sure it is incorrect, mentally rule it out.
- **C.** If unsure, mentally note it as a possible correct answer.

Note

Cisco exams will tell you the number of correct answers. The exam software also helps you finish the question with the right number of answers noted. For example, the software prevents you from selecting too many answers. Also, if you try to move on to the next question, but have too few answers noted, the exam software asks if you truly want to move on.

Use the practice exams as a place to practice your approach to reading. Every time you click to the next question, try to read the question following your approach. If you are feeling time pressure, that is the perfect time to keep practicing your approach, to reduce and eliminate questions you miss because of scanning the question instead of reading thoroughly.

Taking Other Practice Exams

Many people add other practice exams and questions other than the questions that come with this book. Frankly, using other practice exams in addition to the questions that come with this book can be a good idea, for many reasons. The other exam questions can use different terms in different ways, emphasize different topics, and show different scenarios that make you rethink some topics.

No matter where you get additional exam questions, if you use the exam questions for a timed practice exam, it helps to take a few notes about the results. Table 30-5 gives you a place to take those notes. Also, take a guess at the percent of questions you have seen before taking the exam, and note whether you think the questions are less, more, or the same challenge level as the questions that come with this book. And as usual, note whether you ran out of time or had extra time left over at the end.

Table 30-5. Checklist for Practice Exams from Other Sources

Exam Source	Other Exam Notes	% Questions Repeated (Estimate)	Challenging?	Date	Score	Time Notes

Note that the publisher does sell products that include additional test questions. The *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide Premium Edition eBook and Practice Test* product is basically the publisher's eBook version of this book. It includes a soft copy of the book, in formats you can read on your computer or on the most common book readers and tablets. The product includes all the content you would normally get with the DVD that comes with the print book, including all the question databases mentioned in this chapter. Additionally, this product includes two more ICND1 exam databases, plus two more CCNA exam databases, for extra exams.

Note

In addition to getting the extra questions, the Premium editions have links to every test question, including those in the print book, to the specific section of the book for further reference. This is a great learning tool if you need more detail than what you find in the question explanations. You can purchase the eBooks and additional practice exams at 70 percent off the list price using the coupon on the back of the activation code card in the DVD sleeve, making the Premium editions the best and most cost-efficient way to get more practice questions.

Find Knowledge Gaps Through Question Review

You just took a number of practice exams. You probably learned a lot, gained some exam-taking skills, and improved your networking knowledge and skills. But if you go back and look at all the questions you missed, you might be able to find a few small gaps in your knowledge.

One of the hardest things to find when doing your final exam preparation is to discover gaps in your knowledge and skills. In other words, what topics and skills do you need to know that you do not know? Or what topics do you think you know, but you misunderstand about some important fact? Finding gaps in your knowledge at this late stage requires more than just your gut feel about your strengths and weaknesses.

This next task uses a feature of PCPT to help you find those gaps. The PCPT software tracks each practice exam you take, remembering your answer for every question, and whether you got it wrong. You can view the results and move back and forth between seeing the question and seeing the results page. To find gaps in your knowledge, follow these steps:

Step 1. Pick and review one of your practice exams.

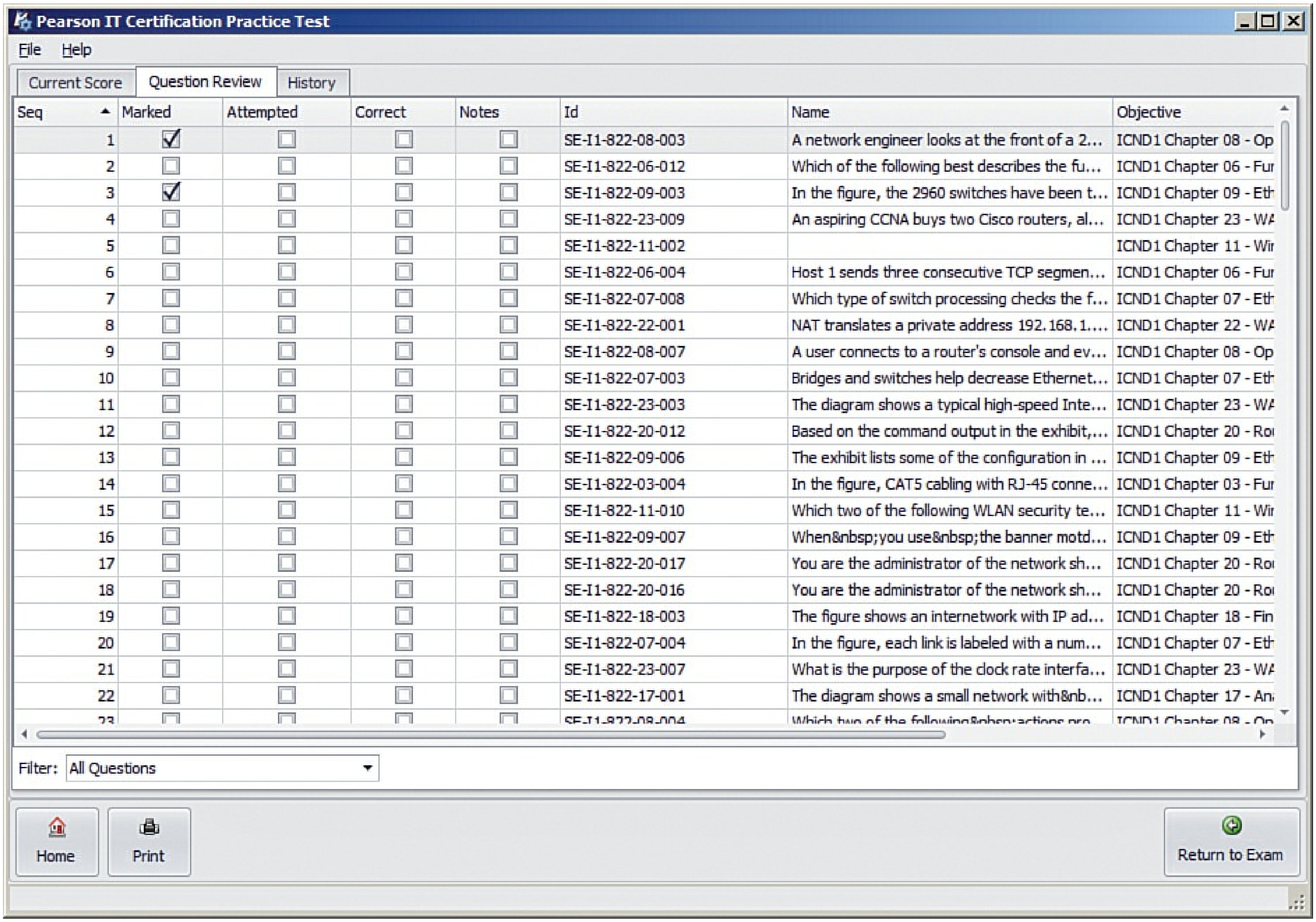
Step 2. Review each incorrect question until you are happy that you understand the question.

Step 3. When finished with your review for a question, mark the question.

Step 4. Review all incorrect questions from your exam until all are marked.

Step 5. Move on to the next practice exam.

Figure 30-2 shows a sample "Question Review" page, in which all the questions were answered incorrectly. The results list a "Correct" column, with no check mark meaning that the answer was incorrect.

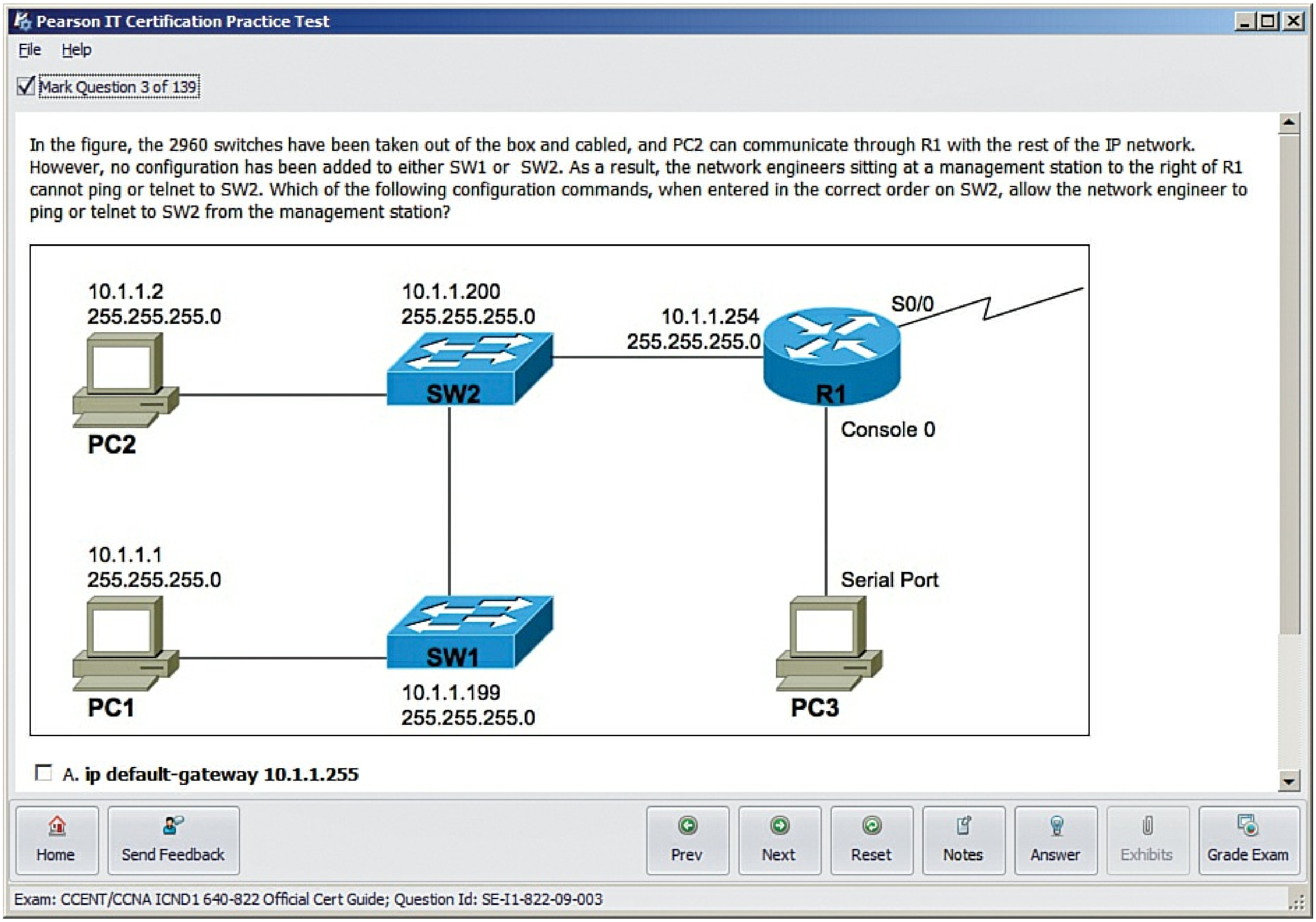


Seq	Marked	Attempted	Correct	Notes	Id	Name	Objective
1	☑	☐	☐	☐	SE-I1-822-08-003	A network engineer looks at the front of a 2...	ICND1 Chapter 08 - Op
2	☐	☐	☐	☐	SE-I1-822-06-012	Which of the following best describes the fu...	ICND1 Chapter 06 - Fur
3	☑	☐	☐	☐	SE-I1-822-09-003	In the figure, the 2960 switches have been t...	ICND1 Chapter 09 - Eth
4	☐	☐	☐	☐	SE-I1-822-23-009	An aspiring CCNA buys two Cisco routers, al...	ICND1 Chapter 23 - WA
5	☐	☐	☐	☐	SE-I1-822-11-002		ICND1 Chapter 11 - Wir
6	☐	☐	☐	☐	SE-I1-822-06-004	Host 1 sends three consecutive TCP segmen...	ICND1 Chapter 06 - Fur
7	☐	☐	☐	☐	SE-I1-822-07-008	Which type of switch processing checks the f...	ICND1 Chapter 07 - Eth
8	☐	☐	☐	☐	SE-I1-822-22-001	NAT translates a private address 192.168.1....	ICND1 Chapter 22 - WA
9	☐	☐	☐	☐	SE-I1-822-08-007	A user connects to a router's console and ev...	ICND1 Chapter 08 - Op
10	☐	☐	☐	☐	SE-I1-822-07-003	Bridges and switches help decrease Ethernet...	ICND1 Chapter 07 - Eth
11	☐	☐	☐	☐	SE-I1-822-23-003	The diagram shows a typical high-speed Inte...	ICND1 Chapter 23 - WA
12	☐	☐	☐	☐	SE-I1-822-20-012	Based on the command output in the exhibit,...	ICND1 Chapter 20 - Rou
13	☐	☐	☐	☐	SE-I1-822-09-006	The exhibit lists some of the configuration in ...	ICND1 Chapter 09 - Eth
14	☐	☐	☐	☐	SE-I1-822-03-004	In the figure, CAT5 cabling with RJ-45 conne...	ICND1 Chapter 03 - Fur
15	☐	☐	☐	☐	SE-I1-822-11-010	Which two of the following WLAN security te...	ICND1 Chapter 11 - Wir
16	☐	☐	☐	☐	SE-I1-822-09-007	When you use the banner motd...	ICND1 Chapter 09 - Eth
17	☐	☐	☐	☐	SE-I1-822-20-017	You are the administrator of the network sh...	ICND1 Chapter 20 - Rou
18	☐	☐	☐	☐	SE-I1-822-20-016	You are the administrator of the network sh...	ICND1 Chapter 20 - Rou
19	☐	☐	☐	☐	SE-I1-822-18-003	The figure shows an internetwork with IP ad...	ICND1 Chapter 18 - Fin
20	☐	☐	☐	☐	SE-I1-822-07-004	In the figure, each link is labeled with a num...	ICND1 Chapter 07 - Eth
21	☐	☐	☐	☐	SE-I1-822-23-007	What is the purpose of the clock rate interfa...	ICND1 Chapter 23 - WA
22	☐	☐	☐	☐	SE-I1-822-17-001	The diagram shows a small network with&nb...	ICND1 Chapter 17 - Ana
23	☐	☐	☐	☐	SE-I1-822-08-004	Which two of the following actions pro...	ICND1 Chapter 08 - Op

Filter: All Questions

Figure 30-2. PCPT Grading Results Page

To perform the process of reviewing questions and marking them as complete, you can move between this Question Review page and the individual questions. Just double-click a question to move back to that question. From the question, you can click "Grade Exam" to move back to the grading results and to the Question Review page shown in Figure 30-2. The question window also shows the place to mark the question, in the upper left, as shown in Figure 30-3.


Pearson IT Certification Practice Test
File
Help
☑ Mark Question 3 of 139
10.1.1.2
255.255.255.0
PC2
10.1.1.200
255.255.255.0
SW2
10.1.1.254
255.255.255.0
R1
S0/0
Console 0
10.1.1.1
255.255.255.0
PC1
SW1
10.1.1.199
255.255.255.0
Serial Port
PC3
Home
Send Feedback
Prev
Next
Reset
Notes
Answer
Exhibits
Grade Exam

In the figure, the 2960 switches have been taken out of the box and cabled, and PC2 can communicate through R1 with the rest of the IP network. However, no configuration has been added to either SW1 or SW2. As a result, the network engineers sitting at a management station to the right of R1 cannot ping or telnet to SW2. Which of the following configuration commands, when entered in the correct order on SW2, allow the network engineer to ping or telnet to SW2 from the management station?

☐ A. **ip default-gateway 10.1.1.255**

Exam: CCENT/CCNA ICND1 640-822 Official Cert Guide; Question Id: SE-I1-822-09-003

Figure 30-3. Reviewing a Question, with Mark Feature in Upper Left

If you want to come back later to look through the questions you missed from an earlier exam, start at the PCPT home screen. From there, instead of clicking the Start button to start a new exam, click the "View Grade History" button to see your earlier exam attempts and work through any missed questions.

Track your progress through your gap review in Table 30-6. PCPT lists your previous practice exams by date and score, so it helps to note those values in the table for comparison to the PCPT menu.

Table 30-6. Tracking Checklist for Gap Review of Practice Exams

Exam (ICND1, ICND2, or CCNA)	Original Practice Exam Date	Original Exam Score	Date Gap Review Was Completed

Practice Hands-On CLI Skills

To do well on Sim and Simlet questions, you need to be comfortable with many Cisco router and switch commands, as well as how to use them from a Cisco CLI. As described in the introduction to this book, Sim questions require you to decide what configuration command(s) need to be configured to fix a problem or to complete a working configuration. Simlet questions require you to answer multichoice questions by first using the CLI to issue **show** commands to look at the status of routers and switches in a small network.

To be ready for the exam, you need to know the following kinds of information:

CLI navigation: Basic CLI mechanics of moving into and out of user, enable, and configuration modes

Individual configuration: The meaning of the parameters of each configuration command

Feature configuration: The set of configuration commands, both required and optional, for each feature

Verification of configuration: The **show** commands that directly identify the configuration settings

Verification of status: The **show** commands that list current status values, and the ability to decide incorrect configuration or other problem causes of less-than-optimal status values

To help remember and review all this knowledge and skill, you can do the tasks listed in the next several pages.

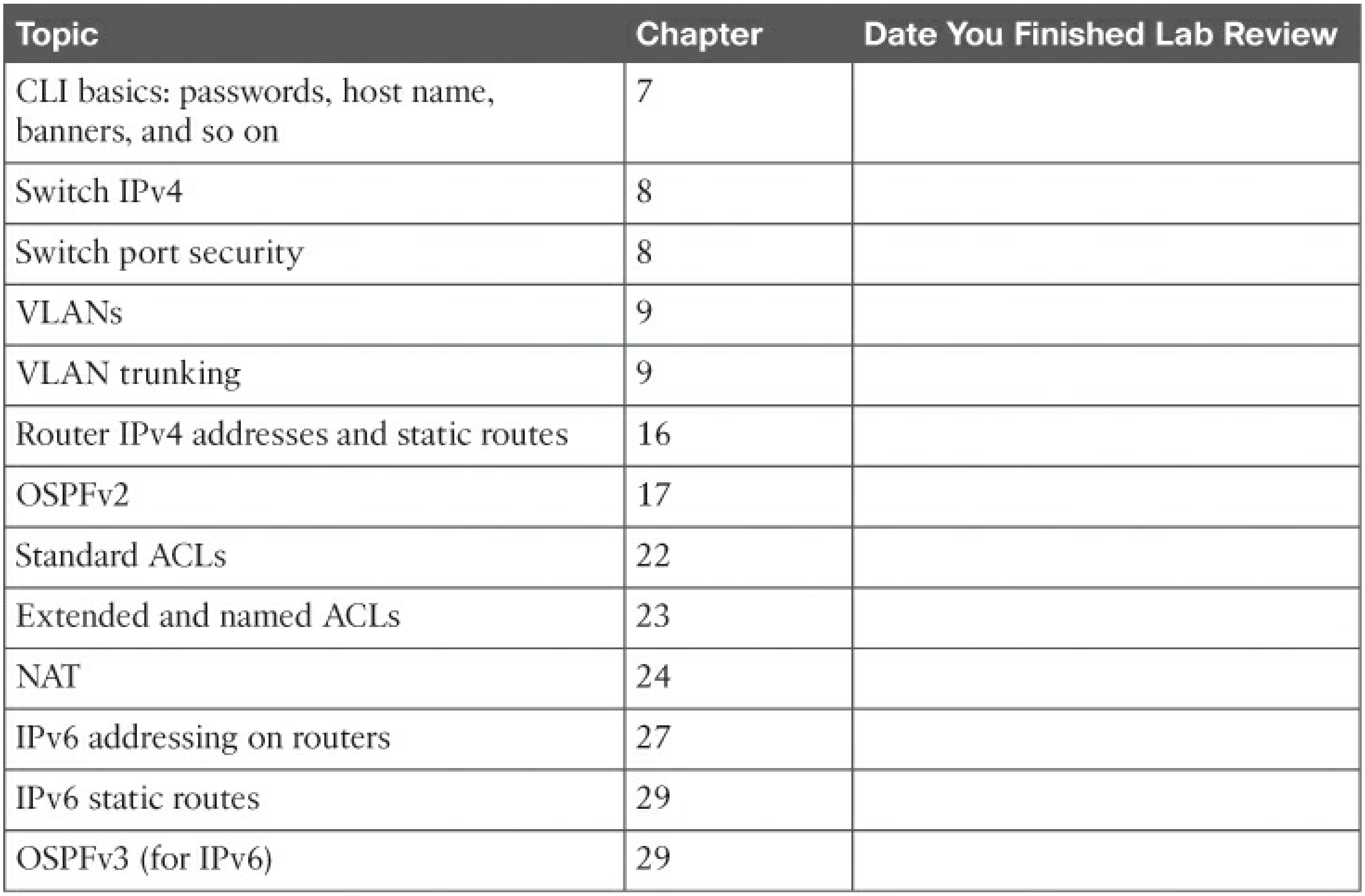
Review Mind Maps from Part Review

During Part Review, you created different mind maps with both configuration and verification commands. To remember the specific mind maps, flip back to each part's Part Review section.

Do Labs

Whatever method you chose for building hands-on CLI skills, take some time to review and do some labs to practice the commands. At this point, you should have thought about configuration quite a bit, whether in a Simulator, on real gear, or even just as paper exercises. While it might be impractical to repeat every lab, make it a point to practice any commands and features for which you feel a little unsure about the topics from your review of the mind maps. Make sure to review lab exercises on the major topics in Table 30-7.

Table 30-7. Lab Checklist



Topic	Chapter	Date You Finished Lab Review
CLI basics: passwords, host name, banners, and so on	7	
Switch IPv4	8	
Switch port security	8	
VLANs	9	
VLAN trunking	9	
Router IPv4 addresses and static routes	16	
OSPFv2	17	
Standard ACLs	22	
Extended and named ACLs	23	
NAT	24	
IPv6 addressing on routers	27	
IPv6 static routes	29	
OSPFv3 (for IPv6)	29	

One great way to practice is to use the Pearson Network Simulator (the Sim) at pearsonitcertification.com/networksimulator.

As a free alternative, you can do some short 5–10-minute paper configuration labs listed on the author's blogs. Just browse the Config Museum labs in those blogs (one blog for ICND1 and one for ICND2), and choose the labs you want to use. You can try these on paper or on your own lab gear. To find the blogs, start at www.certskills.com/blogs.

Other Study Tasks

If you get to this point, and still feel the need to prepare some more, this last topic gives you three suggestions.

First, the chapter review Exam Preparation Tasks and Part Review sections give you some useful study tasks.

Second, take more exam questions from other sources. You can always get more questions in the Cisco Press Premium Edition eBook and Practice Test products, which include an eBook copy of this book plus additional questions in additional PCPT exam banks. However, you can search the Internet for questions from many sources, and review those questions as well.

Note

Some vendors claim to sell practice exams that contain the literal exam questions from the exam. These exams, called "brain dumps," are against the Cisco testing policies. Cisco strongly discourages using any such tools for study.

Finally, join in the discussions on the Cisco Learning Network. Try to answer questions asked by other learners; the process of answering makes you think much harder about the topic. When someone posts an answer with which you disagree, think about why and talk about it online. This is a great way to both learn more and build confidence.

Final Thoughts

You have studied quite a bit, worked hard, and sacrificed time and money to be ready for the exam. I hope your exam goes well, that you pass, and that you pass because you really know your stuff and will do well in your IT and networking career.

I would encourage you to celebrate when you pass, and ask advice when you do not. The Cisco Learning Network is a great place to make posts to celebrate and to ask advice for the next time around. I personally would love to hear about your progress through Twitter (@wendellodom) or my Facebook fan page (facebook.com/wendellodom). I wish you well, and congratulations for working through the entire book!

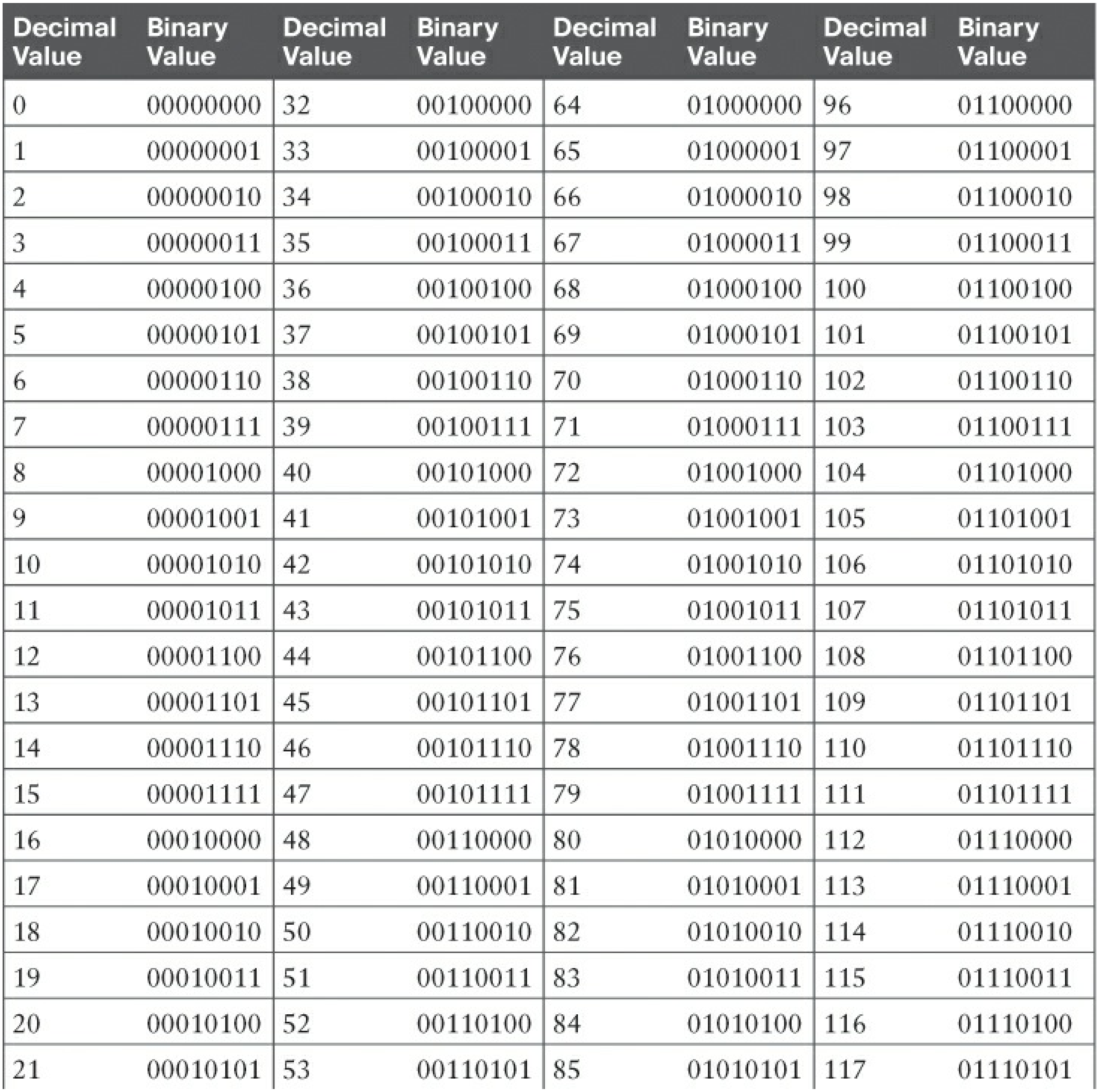
Part IX: Appendixes

Appendix A: Numeric Reference Tables
Appendix B: ICND1 Exam Updates
Glossary

Appendix A. Numeric Reference Tables

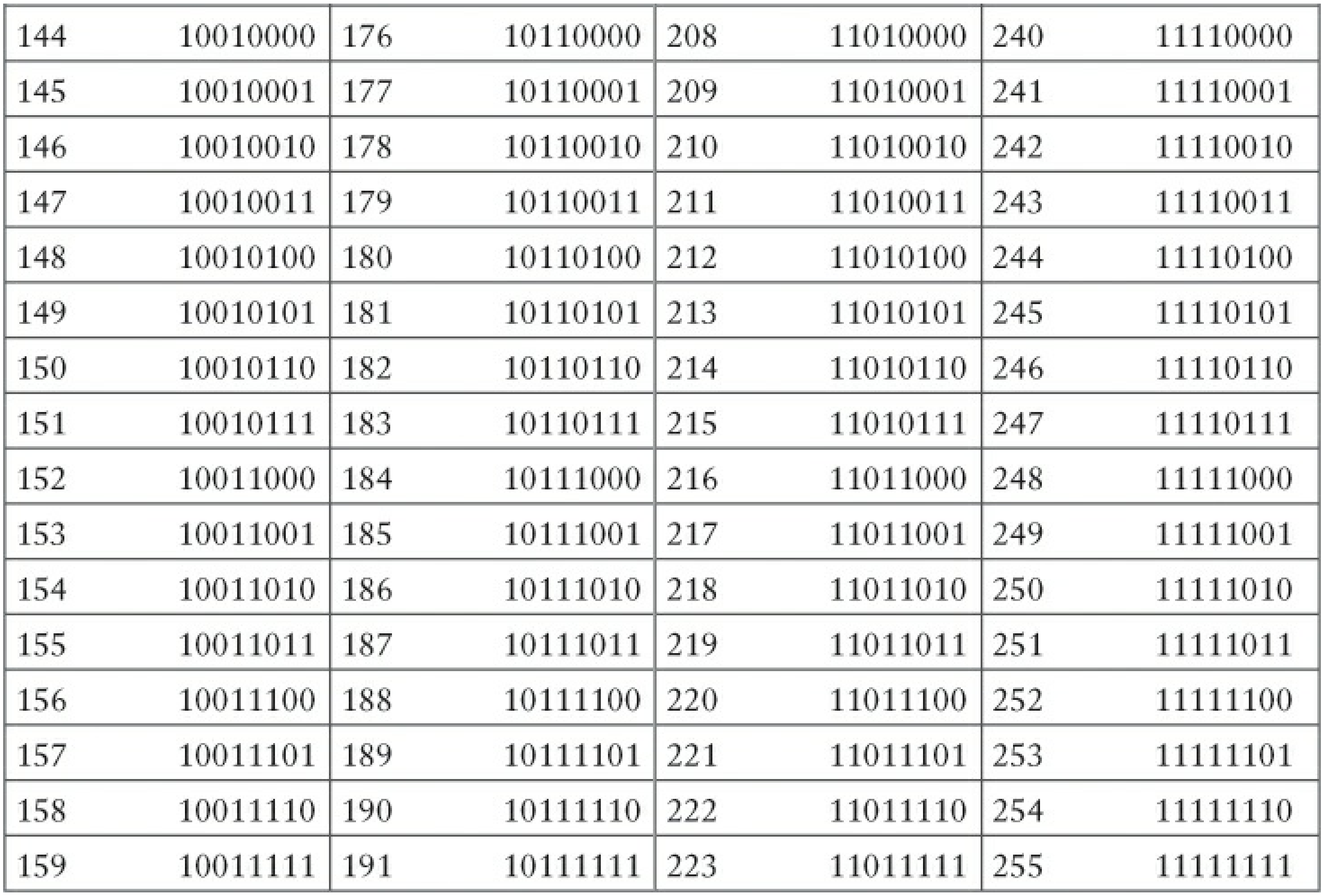
This appendix provides several useful reference tables that list numbers used throughout this book. Specifically: Table A-1: A decimal-binary cross reference, useful when converting from decimal to binary and vice versa.

Table A-1. Decimal-Binary Cross Reference, Decimal Values 0–255



Decimal Value	Binary Value	Decimal Value	Binary Value	Decimal Value	Binary Value	Decimal Value	Binary Value
0	00000000	32	00100000	64	01000000	96	01100000
1	00000001	33	00100001	65	01000001	97	01100001
2	00000010	34	00100010	66	01000010	98	01100010
3	00000011	35	00100011	67	01000011	99	01100011
4	00000100	36	00100100	68	01000100	100	01100100
5	00000101	37	00100101	69	01000101	101	01100101
6	00000110	38	00100110	70	01000110	102	01100110
7	00000111	39	00100111	71	01000111	103	01100111
8	00001000	40	00101000	72	01001000	104	01101000
9	00001001	41	00101001	73	01001001	105	01101001
10	00001010	42	00101010	74	01001010	106	01101010
11	00001011	43	00101011	75	01001011	107	01101011
12	00001100	44	00101100	76	01001100	108	01101100
13	00001101	45	00101101	77	01001101	109	01101101
14	00001110	46	00101110	78	01001110	110	01101110
15	00001111	47	00101111	79	01001111	111	01101111
16	00010000	48	00110000	80	01010000	112	01110000
17	00010001	49	00110001	81	01010001	113	01110001
18	00010010	50	00110010	82	01010010	114	01110010
19	00010011	51	00110011	83	01010011	115	01110011
20	00010100	52	00110100	84	01010100	116	01110100
21	00010101	53	00110101	85	01010101	117	01110101

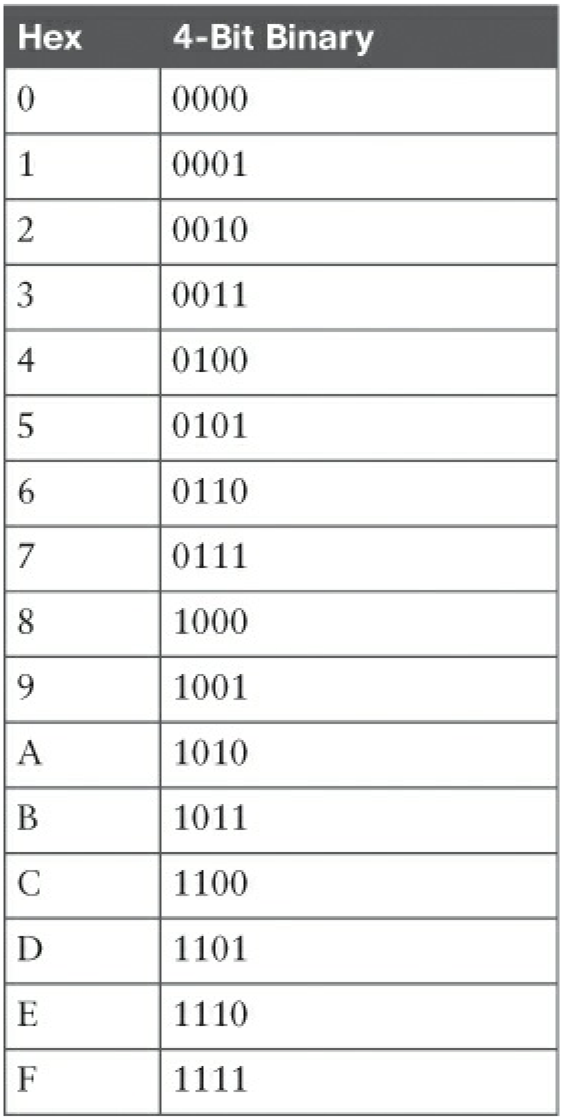
22	00010110	54	00110110	86	01010110	118	01110110
23	00010111	55	00110111	87	01010111	119	01110111
24	00011000	56	00111000	88	01011000	120	01111000
25	00011001	57	00111001	89	01011001	121	01111001
26	00011010	58	00111010	90	01011010	122	01111010
27	00011011	59	00111011	91	01011011	123	01111011
28	00011100	60	00111100	92	01011100	124	01111100
29	00011101	61	00111101	93	01011101	125	01111101
30	00011110	62	00111110	94	01011110	126	01111110
31	00011111	63	00111111	95	01011111	127	01111111
128	10000000	160	10100000	192	11000000	224	11100000
129	10000001	161	10100001	193	11000001	225	11100001
130	10000010	162	10100010	194	11000010	226	11100010
131	10000011	163	10100011	195	11000011	227	11100011
132	10000100	164	10100100	196	11000100	228	11100100
133	10000101	165	10100101	197	11000101	229	11100101
134	10000110	166	10100110	198	11000110	230	11100110
135	10000111	167	10100111	199	11000111	231	11100111
136	10001000	168	10101000	200	11001000	232	11101000
137	10001001	169	10101001	201	11001001	233	11101001
138	10001010	170	10101010	202	11001010	234	11101010
139	10001011	171	10101011	203	11001011	235	11101011
140	10001100	172	10101100	204	11001100	236	11101100
141	10001101	173	10101101	205	11001101	237	11101101
142	10001110	174	10101110	206	11001110	238	11101110
143	10001111	175	10101111	207	11001111	239	11101111



144	10010000	176	10110000	208	11010000	240	11110000
145	10010001	177	10110001	209	11010001	241	11110001
146	10010010	178	10110010	210	11010010	242	11110010
147	10010011	179	10110011	211	11010011	243	11110011
148	10010100	180	10110100	212	11010100	244	11110100
149	10010101	181	10110101	213	11010101	245	11110101
150	10010110	182	10110110	214	11010110	246	11110110
151	10010111	183	10110111	215	11010111	247	11110111
152	10011000	184	10111000	216	11011000	248	11111000
153	10011001	185	10111001	217	11011001	249	11111001
154	10011010	186	10111010	218	11011010	250	11111010
155	10011011	187	10111011	219	11011011	251	11111011
156	10011100	188	10111100	220	11011100	252	11111100
157	10011101	189	10111101	221	11011101	253	11111101
158	10011110	190	10111110	222	11011110	254	11111110
159	10011111	191	10111111	223	11011111	255	11111111

Table A-2: A hexadecimal-binary cross reference, useful when converting from hex to binary and vice versa.

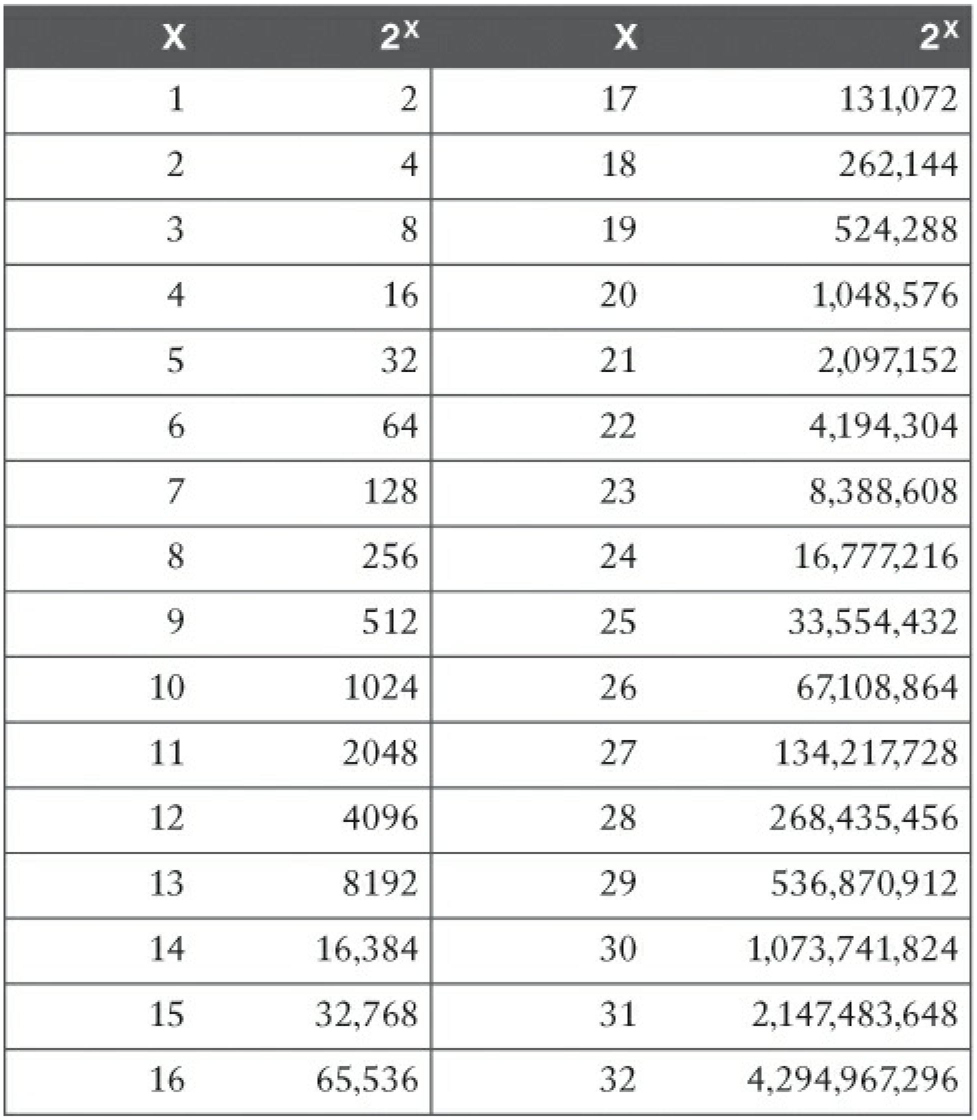
Table A-2. Hex-Binary Cross Reference



Hex	4-Bit Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
A	1010
B	1011
C	1100
D	1101
E	1110
F	1111

Table A-3: Powers of 2, from 2^1 through 2^{32}.

Table A-3. Powers of 2



X	2^X	X	2^X
1	2	17	131,072
2	4	18	262,144
3	8	19	524,288
4	16	20	1,048,576
5	32	21	2,097,152
6	64	22	4,194,304
7	128	23	8,388,608
8	256	24	16,777,216
9	512	25	33,554,432
10	1024	26	67,108,864
11	2048	27	134,217,728
12	4096	28	268,435,456
13	8192	29	536,870,912
14	16,384	30	1,073,741,824
15	32,768	31	2,147,483,648
16	65,536	32	4,294,967,296

Table A-4: Table of all 33 possible subnet masks, in all three formats.

Table A-4. All Subnet Masks

Decimal	Prefix	Binary
0.0.0.0	/0	00000000 00000000 00000000 00000000
128.0.0.0	/1	10000000 00000000 00000000 00000000
192.0.0.0	/2	11000000 00000000 00000000 00000000
224.0.0.0	/3	11100000 00000000 00000000 00000000
240.0.0.0	/4	11110000 00000000 00000000 00000000
248.0.0.0	/5	11111000 00000000 00000000 00000000
252.0.0.0	/6	11111100 00000000 00000000 00000000
254.0.0.0	/7	11111110 00000000 00000000 00000000
255.0.0.0	/8	11111111 00000000 00000000 00000000
255.128.0.0	/9	11111111 10000000 00000000 00000000
255.192.0.0	/10	11111111 11000000 00000000 00000000
255.224.0.0	/11	11111111 11100000 00000000 00000000
255.240.0.0	/12	11111111 11110000 00000000 00000000
255.248.0.0	/13	11111111 11111000 00000000 00000000
255.252.0.0	/14	11111111 11111100 00000000 00000000
255.254.0.0	/15	11111111 11111110 00000000 00000000
255.255.0.0	/16	11111111 11111111 00000000 00000000
255.255.128.0	/17	11111111 11111111 10000000 00000000
255.255.192.0	/18	11111111 11111111 11000000 00000000
255.255.224.0	/19	11111111 11111111 11100000 00000000
255.255.240.0	/20	11111111 11111111 11110000 00000000
255.255.248.0	/21	11111111 11111111 11111000 00000000
255.255.252.0	/22	11111111 11111111 11111100 00000000
255.255.254.0	/23	11111111 11111111 11111110 00000000
255.255.255.0	/24	11111111 11111111 11111111 00000000
255.255.255.128	/25	11111111 11111111 11111111 10000000
255.255.255.192	/26	11111111 11111111 11111111 11000000
255.255.255.224	/27	11111111 11111111 11111111 11100000
255.255.255.240	/28	11111111 11111111 11111111 11110000
255.255.255.248	/29	11111111 11111111 11111111 11111000
255.255.255.252	/30	11111111 11111111 11111111 11111100
255.255.255.254	/31	11111111 11111111 11111111 11111110
255.255.255.255	/32	11111111 11111111 11111111 11111111

Appendix B. ICND1 Exam Updates

Over time, reader feedback allows Cisco Press to gauge which topics give our readers the most problems when taking the exams. Additionally, Cisco might make small changes in the breadth of exam topics or in the emphasis of certain topics. To assist readers with those topics, the author creates new materials clarifying and expanding upon those troublesome exam topics.

The document you are viewing is Version 1.0 of this appendix and there are no updates. You can check for an updated version at www.ciscopress.com/title/9781587143854.

Glossary

10BASE-T

The 10-Mbps baseband Ethernet specification using two pairs of twisted-pair cabling (Categories 3, 4, or 5): One pair transmits data and the other receives data. 10BASE-T, which is part of the IEEE 802.3 specification, has a distance limit of approximately 100 m (328 feet) per segment.

100BASE-T

A name for the IEEE Fast Ethernet standard that uses two-pair copper cabling, a speed of 100 Mbps, and a maximum cable length of 100 meters.

1000BASE-T

A name for the IEEE Gigabit Ethernet standard that uses four-pair copper cabling, a speed of 1000 Mbps (1 Gbps), and a maximum cable length of 100 meters.

802.1Q

The IEEE standardized protocol for VLAN trunking.

802.11a

The IEEE standard for wireless LANs using the U-NII spectrum, OFDM encoding, at speeds of up to 54 Mbps.

802.11b

The IEEE standard for wireless LANs using the ISM spectrum, DSSS encoding, and speeds of up to 11 Mbps.

802.11g

The IEEE standard for wireless LANs using the ISM spectrum, OFDM or DSSS encoding, and speeds of up to 54 Mbps.

802.11n

The IEEE standard for wireless LANs using the ISM spectrum, OFDM encoding, and multiple antennas for single-stream speeds up to 150 Mbps.

A

AAA

Authentication, authorization, and accounting. Authentication confirms the identity of the user or device. Authorization determines what the user or device is allowed to do. Accounting records information about access attempts, including inappropriate requests.

access interface

A LAN network design term that refers to a switch interface connected to end-user devices, configured so that it does not use VLAN trunking.

access link

In Frame Relay, the physical serial link that connects a Frame Relay DTE device, usually a router, to a Frame Relay switch. The access link uses the same physical layer standards as do point-to-point leased lines.

access point

A wireless LAN device that provides a means for wireless clients to send data to each other and to the rest of a wired network, with the AP connecting to both the wireless LAN and the wired Ethernet LAN.

accounting

In security, the recording of access attempts. *See* AAA.

address block

In both IPv4 and IPv6, a set of consecutive addresses. This term is typically used for public addresses, assigned by some numbering authority (IANA/ICANN, an RIR, or an ISP).

adjacent-layer interaction

The general topic of how on one computer, two adjacent layers in a networking architectural model work together, with the lower layer providing services to the higher layer.

administrative distance

In Cisco routers, a means for one router to choose between multiple routes to reach the same subnet when those routes were learned by different routing protocols. The lower the administrative distance, the better the source of the routing information.

ADSL

Asymmetric digital subscriber line. One of many DSL technologies, ADSL is designed to deliver more bandwidth downstream (from the central office to the customer site) than upstream.

All-nodes multicast address

A specific IPv6 multicast address, FF02::1, with link-local scope, used to send packets to all devices on the link that support IPv6.

All-routers multicast address

A specific IPv6 multicast address, FF02::2, with link-local scope, used to send packets to all devices that act as IPv6 routers on the local link.

Anti-X

The term used by Cisco to refer to a variety of security tools that help prevent various attacks, including antivirus, antiphishing, and antispam.

Area Border Router (ABR)

A router using OSPF in which the router has interfaces in multiple OSPF areas.

ARP

Address Resolution Protocol. An Internet protocol used to map an IP address to a MAC address. Defined in RFC 826.

ARP table

A list of IP addresses of neighbors on the same VLAN, along with their MAC addresses, as kept in memory by hosts and routers.

ARPANET

The first packet-switched network, first created around 1970, which served as the predecessor to the Internet.

asymmetric

A feature of many Internet access technologies, including DSL, cable, and modems, in which the downstream transmission rate is higher than the upstream transmission rate.

asynchronous

The lack of an imposed time ordering on a bit stream. Practically, both sides agree to the same speed, but there is no check or adjustment of the rates if they are slightly different. However, because only 1 byte per transfer is sent, slight differences in clock speed are not an issue.

ATM

Asynchronous Transfer Mode. The international standard for cell relay in which multiple service types (such as voice, video, and data) are conveyed in fixed-length (53-byte) cells. Fixed-length cells allow cell processing to occur in hardware, thereby reducing transit delays.

authentication

In security, the verification of the identity of a person or a process. *See* AAA.

authorization

In security, the determination of the rights allowed for a particular user or device. *See* AAA.

autonegotiation

An IEEE standard mechanism (802.3u) with which two nodes can exchange messages for the purpose of choosing to use the same Ethernet standards on both ends of the link, ensuring that the link functions and functions well.

autonomous system

An internetwork in the administrative control of one organization, company, or governmental agency, inside which that organization typically runs an interior gateway protocol (IGP).

auxiliary port

A physical connector on a router that is designed to be used to allow a remote terminal, or PC with a terminal emulator, to access a router using an analog modem.

B

back-to-back link

A serial link between two routers, created without CSU/DSUs, by connecting a DTE cable to one router and a DCE cable to the other. Typically used in labs to build serial links without the expense of an actual leased line from the telco.

balanced hybrid

A term that, over the years, has been used to refer to the logic behind the EIGRP routing protocol. More commonly today, this logic is referred to as advanced distance vector logic.

bandwidth

A reference to the speed of a networking link. Its origins come from earlier communications technology in which the range, or width, of the frequency band dictated how fast communications could occur.

basic service set (BSS)

In wireless LANs, a WLAN with a single access point.

bitwise Boolean AND

A Boolean AND between two numbers of the same length in which the first bit in each number is ANDed, and then the second bit in each number, and then the third, and so on.

Boolean AND

A math operation performed on a pair of one-digit binary numbers. The result is another one-digit binary number. 1 AND 1 yields 1; all other combinations yield a 0.

boot field

The low-order 4 bits of the configuration register in a Cisco router. The value in the boot field in part tells the router where to look for a Cisco IOS image to load.

broadcast address

Generally, any address that represents all devices, and can be used to send one message to all devices. In Ethernet, the MAC address of all binary 1s, or FFFF.FFFF.FFFF in hex. For IPv4, *see* subnet broadcast address.

broadcast domain

A set of all devices that receive broadcast frames originating from any device within the set. Devices in the same VLAN are in the same broadcast domain.

broadcast frame

An Ethernet frame sent to destination address FFFF.FFFF.FFFF, meaning that the frame should be delivered to all hosts on that LAN.

broadcast subnet

When subnetting a Class A, B, or C network, the one subnet in each classful network for which all subnet bits have a value of binary 1. The subnet broadcast address in this subnet has the same numeric value as the classful network's network-wide broadcast address.

bus

A common physical signal path composed of wires or other media across which signals can be sent from one part of a computer to another.

C

cable internet

An Internet access technology that uses a cable TV (CATV) cable, normally used for video, to send and receive data.

CDP

Cisco Discovery Protocol. A media-and protocol-independent device-discovery protocol that runs on most Cisco-manufactured equipment, including routers, access servers, and switches. Using CDP, a device can advertise its existence to other devices and receive information about other devices on the same LAN or on the remote side of a WAN.

CDP neighbor

A device on the other end of some communications cable that is advertising CDP updates.

CIDR

Classless interdomain routing. An RFC-standard tool for global IP address range assignment. CIDR reduces the size of Internet routers' IP routing tables, helping deal with the rapid growth of the Internet. The term *classless* refers to the fact that the summarized groups of networks represent a group of addresses that do not conform to IPv4 classful (Class A, B, and C) grouping rules.

CIDR notation

See prefix notation.

circuit switching

A generic reference to network services, typically WAN services, in which the provider sets up a (Layer 1) circuit between two devices, and the provider makes no attempt to interpret the meaning of the bits. *See also* packet switching.

Cisco Express Forwarding (CEF)

A method of internal processing on Cisco routers, meant to make the routing process very efficient, doing so by caching IP routes in a table that can be searched very quickly, and by remembering data link headers rather than building them for every packet that is forwarded.

classful IP network

An IPv4 Class A, B, or C network; called a classful network because these networks are defined by the class rules for IPv4 addressing.

classful routing protocol

Does not transmit the mask information along with the subnet number, and therefore must consider Class A, B, and C network boundaries and perform autosummarization at those boundaries. Does not support VLSM.

classless routing protocol

An inherent characteristic of a routing protocol, specifically that the routing protocol does send subnet masks in its routing updates, thereby removing any need to make assumptions about the addresses in a particular subnet or network, making it able to support VLSM and manual route summarization.

CLI

Command-line interface. An interface that enables the user to interact with the operating system by entering commands and optional arguments.

clock rate

The speed at which a serial link encodes bits on the transmission medium.

clock source

The device to which the other devices on the link adjust their speed when using synchronous links.

clocking

The process of supplying a signal over a cable, either on a separate pin on a serial cable or as part of the signal transitions in the transmitted signal, so that the receiving device can keep synchronization with the sending device.

codec

Coder-decoder. An integrated circuit device that transforms analog voice signals into a digital bit stream and then transforms digital signals back into analog voice signals.

collision domain

A set of network interface cards (NIC) for which a frame sent by one NIC could result in a collision with a frame sent by any other NIC in the same collision domain.

command-line interface

See CLI.

configuration mode

A part of the Cisco IOS Software CLI in which the user can type configuration commands that are then added to the device's currently used configuration file (running config).

configuration register

In Cisco routers, a 16-bit, user-configurable value that determines how the router functions during initialization. In software, the bit position is set by specifying a hexadecimal value using configuration commands.

connected

The single-item status code listed by a switch **show interfaces status** command, with this status referring to a working interface.

connected route

On a router, an IP route added to the routing table when the router interface is both up and has an IP address configured. The route is for the subnet that can be calculated based on the configured IP address and mask.

connection establishment

The process by which a connection-oriented protocol creates a connection. With TCP, a connection is established by a three-way transmission of TCP segments.

console port

A physical socket on a router or switch to which a cable can be connected between a computer and the router/switch, for the purpose of allowing the computer to use a terminal emulator and use the CLI to configure, verify, and troubleshoot the router/switch.

convergence

The time required for routing protocols to react to changes in the network, removing bad routes and adding new, better routes so that the current best routes are in all the routers' routing tables.

CPE

Customer premises equipment. Any equipment related to communications that is located at the customer site, as opposed to inside the telephone company's network.

crossover cable

An Ethernet cable that swaps the pair used for transmission on one device to a pair used for receiving on the device on the opposite end of the cable. In 10BASE-T and 100BASE-TX networks, this cable swaps the pair at pins 1,2 to pins 3,6 on the other end of the cable, and the pair at pins 3,6 to pins 1,2 as well.

CSMA/CD

Carrier sense multiple access with collision detection. A media-access mechanism in which devices ready to transmit data first check the channel for a carrier. If no carrier is sensed for a specific period of time, a device can transmit. If two devices transmit at once, a collision occurs and is detected by all colliding devices. This collision subsequently delays retransmissions from those devices for some random length of time.

CSU/DSU

Channel service unit/data service unit. A device that understands the Layer 1 details of serial links installed by a telco and how to use a serial cable to communicate with networking equipment such as routers.

cut-through switching

One of three options for internal processing on some models of Cisco LAN switches in which the frame is forwarded as soon as enough of the Ethernet header has been received for the switch to make a forwarding decision, including forwarding the first bits of the frame before the whole frame is received.

D

DCE

Data communications equipment. From a physical layer perspective, the device providing the clocking on a WAN link, typically a CSU/DSU, is the DCE. From a packet-switching perspective, the service provider's switch, to which a router might connect, is considered the DCE.

deencapsulation

On a computer that receives data over a network, the process in which the device interprets the lower-layer headers and, when finished with each header, removes the header, revealing the next-higher-layer PDU.

default gateway/default router

On an IP host, the IP address of some router to which the host sends packets when the packet's destination address is on a subnet other than the local subnet.

default mask

The mask used in a Class A, B, or C network that does not create any subnets; specifically, mask 255.0.0.0 for Class A networks, 255.255.0.0 for Class B networks, and 255.255.255.0 for Class C networks.

default route

On a router, the route that is considered to match all packets that are not otherwise matched by some more specific route.

demarc

The legal term for the demarcation or separation point between the telco's equipment and the customer's equipment.

denial of service (DoS)

A type of attack whose goal is to cause problems by preventing legitimate users from being able to access services, thereby preventing the normal operation of computers and networks.

DHCP

Dynamic Host Configuration Protocol. A protocol used by hosts to dynamically discover and lease an IP address, and learn the correct subnet mask, default gateway, and DNS server IP addresses.

DHCP Client

Any device that uses DHCP protocols to ask to lease an IP address from a DHCP server, or to learn any IP settings from that server.

DHCP Relay

The name of the router IOS feature that forwards DHCP messages from client to servers by changing the destination IP address from 255.255.255.255 to the IP address of the DHCP server.

DHCP Server

Software that waits for DHCP clients to request to lease IP addresses, with the server assigning a lease of an IP address as well as listing other important IP settings for the client.

directed broadcast address

See subnet broadcast address.

distance vector

The logic behind the behavior of some interior routing protocols, such as RIP. Distance vector routing algorithms call for each router to send its entire routing table in each update, but only to its neighbors. Distance vector routing algorithms can be prone to routing loops but are computationally simpler than link-state routing algorithms.

DNS

Domain Name System. An application layer protocol used throughout the Internet for translating host names into their associated IP addresses.

dotted-decimal notation (DDN)

The format used for IP version 4 addresses, in which four decimal values are used, separated by periods (dots).

DS0

Digital signal level 0. A 64-kbps line, or channel of a faster line inside a telco, whose origins are to support a single voice call using the original voice (PCM) codecs.

DS1

Digital signal level 1. A 1.544-Mbps line from the telco, with 24 DS0 channels of 64 kbps each, plus an 8-kbps management and framing channel. Also called a T1.

DS3

Digital signal level 3. A 44.736-Mbps line from the telco, with 28 DS1 channels plus overhead. Also called a T3.

DSL

Digital subscriber line. Public network technology that delivers high bandwidth over conventional telco local-loop copper wiring at limited distances. Typically used as an Internet access technology, connecting a user to an ISP.

DSL modem

A device that connects to a telephone line, using DSL standards, to transmit and receive data to/from a telco using DSL.

DTE

Data terminal equipment. From a Layer 1 perspective, the DTE synchronizes its clock based on the clock sent by the DCE. From a packet-switching perspective, the DTE is the device outside the service provider's network, typically a router.

dual stack

A mode of operation in which a host or router runs both IPv4 and IPv6.

duplex mismatch

On opposite ends of any Ethernet link, the condition in which one of the two devices uses full-duplex logic and the other uses half-duplex logic, resulting in unnecessary frame discards and retransmissions on the link.

Duplicate Address Detection (DAD)

A term used in IPv6 to refer to how hosts first check whether another host is using a unicast address before the first host uses that address.

E

E1

Similar to a T1, but used in Europe. It uses a rate of 2.048 Mbps and 32 64-kbps channels, with one channel reserved for framing and other overhead.

EIGRP

Enhanced Interior Gateway Routing Protocol. An advanced version of IGRP developed by Cisco. Provides superior convergence properties and operating efficiency and combines the advantages of link-state protocols with those of distance vector protocols.

EIGRP version 6

The version of the EIGRP routing protocol that supports IPv6, and not IPv4.

enable mode

A part of the Cisco IOS CLI in which the user can use the most powerful and potentially disruptive commands on a router or switch, including the ability to then reach configuration mode and reconfigure the router.

encapsulation

The placement of data from a higher-layer protocol behind the header (and in some cases, between a header and trailer) of the next-lower-layer protocol. For example, an IP packet could be encapsulated in an Ethernet header and trailer before being sent over an Ethernet.

encryption

Applying a specific algorithm to data to alter the appearance of the data, making it incomprehensible to those who are not authorized to see the information.

error detection

The process of discovering whether a data link level frame was changed during transmission. This process typically uses a Frame Check Sequence (FCS) field in the data link trailer.

error disabled

An interface state on LAN switches that can be the result of one of many security violations.

error recovery

The process of noticing when some transmitted data was not successfully received and resending the data until it is successfully received.

Ethernet

A series of LAN standards defined by the IEEE, originally invented by Xerox Corporation and developed jointly by Xerox, Intel, and Digital Equipment Corporation.

Ethernet address

A 48-bit (6-byte) binary number, usually written as a 12-digit hexadecimal number, used to identify Ethernet nodes in an Ethernet network. Ethernet frame headers list a destination and source address field, used by the Ethernet devices to deliver Ethernet frames to the correct destination.

Ethernet frame

A term referring to an Ethernet data link header and trailer, plus the data encapsulated between the header and trailer.

Ethernet link

A generic term for any physical link between two Ethernet nodes, no matter what type of cabling is used.

Ethernet port

A generic term for the opening on the side of any Ethernet node, typically in an Ethernet NIC or LAN switch, into which an Ethernet cable can be connected.

EtherType

Jargon that shortens the term "Ethernet Type," which refers to the Type field in the Ethernet header. The Type field identifies the type of packet encapsulated inside an Ethernet frame.

EUI-64

Literally, a standard for an extended unique identifier that is 64 bits long. Specifically for IPv6, a set of rules for forming the a 64-bit identifier, used as the interface ID in IPv6 addresses, by starting with a 48-bit MAC address, inserting FFFE (hex) in the middle, and inverting the seventh bit.

extended access list

A list of IOS **access-list** global configuration commands that can match multiple parts of an IP packet, including the source and destination IP address and TCP/UDP ports, for the purpose of deciding which packets to discard and which to allow through the router.

exterior gateway protocol (EGP)

A routing protocol that was designed to exchange routing information between different autonomous systems.

F

Fast Ethernet

The common name for all the IEEE standards that send data at 100 megabits per second.

filter

Generally, a process or a device that screens network traffic for certain characteristics, such as source address, destination address, or protocol, and determines whether to forward or discard that traffic based on the established criteria.

firewall

A device that forwards packets between the less secure and more secure parts of the network, applying rules that determine which packets are allowed to pass, and which are not.

flash

A type of read/write permanent memory that retains its contents even with no power applied to the memory, and uses no moving parts, making the memory less likely to fail over time.

flooding

The result of the LAN switch forwarding process for broadcasts and unknown unicast frames. Switches forward these frames out all interfaces, except the interface in which the frame arrived. Switches also flood multicasts by default, although this behavior can be changed.

flow control

The process of regulating the amount of data sent by a sending computer toward a receiving computer. Several flow control mechanisms exist, including TCP flow control, which uses windowing.

forward

To send a frame received in one interface out another interface, toward its ultimate destination.

forward acknowledgment

A process used by protocols that do error recovery, in which the number that acknowledges data lists the next data that should be sent, not the last data that was successfully received.

four-wire circuit

A line from the telco with four wires, composed of two twisted-pair wires. Each pair is used to send in one direction, so a four-wire circuit allows full-duplex communication.

fragment-free switching

One of three internal processing options on some Cisco LAN switches in which the first bits of the frame can be forwarded before the entire frame is received, but not until the first 64 bytes of the frame are received, in which case, in a well-designed LAN, collision fragments should not occur as a result of this forwarding logic.

frame

A term referring to a data link header and trailer, plus the data encapsulated between the header and trailer.

Frame Check Sequence

A field in many data link trailers used as part of the error-detection process.

Frame Relay

An international standard data link protocol that defines the capabilities to create a frame-switched (packet-switched) service, allowing DTE devices (typically routers) to send data to many other devices using a single physical connection to the Frame Relay service.

Frequency Hopping Spread Spectrum

A method of encoding data on a wireless LAN in which consecutive transmissions occur on different nearby frequency bands as compared with the prior transmission. Not used in modern WLAN standards.

full-duplex

Generically, any communication in which two communicating devices can concurrently send and receive data. In Ethernet LANs, the allowance for both devices to send and receive at the same time, allowed when both devices disable their CSMA/CD logic.

full mesh

A network topology in which more than two devices can physically communicate and, by choice, all pairs of devices are allowed to communicate directly.

G

Gigabit Ethernet

The common name for all the IEEE standards that send data at 1 gigabit per second.

global routing prefix

An IPv6 prefix that defines an IPv6 address block made up of global unicast addresses, assigned to one organization, so that the organization has a block of globally unique IPv6 addresses to use in its network.

global unicast address

A type of unicast IPv6 address that has been allocated from a range of public globally unique IP addresses, as registered through IANA/ICANN, its member agencies, and other registries or ISPs.

H

half-duplex

Generically, any communication in which only one device at a time can send data. In Ethernet LANs, the normal result of the CSMA/CD algorithm that enforces the rule that only one device should send at any point in time.

HDLC

High-Level Data Link Control. A bit-oriented synchronous data link layer protocol developed by the International Organization for Standardization (ISO).

head end

The upstream, transmit end of a cable TV (CATV) installation.

header

In computer networking, a set of bytes placed in front of some other data, encapsulating that data, as defined by a particular protocol.

host

Any device that uses an IP address.

host address

The IP address assigned to a network card on a computer.

host name

The alphameric name of an IP host.

host part

A term used to describe a part of an IPv4 address that is used to uniquely identify a host inside a subnet. The host part is identified by the bits of value 0 in the subnet mask.

host route

A route with a /32 mask, which by virtue of this mask represents a route to a single host IP address.

HTML

Hypertext Markup Language. A simple document-formatting language that uses tags to indicate how a given part of a document should be interpreted by a viewing application, such as a web browser.

HTTP

Hypertext Transfer Protocol. The protocol used by web browsers and web servers to transfer files, such as text and graphic files.

hub

A LAN device that provides a centralized connection point for LAN cabling, repeating any received electrical signal out all other ports, thereby creating a logical bus. Hubs do not interpret the electrical signals as a frame of bits, so hubs are considered to be Layer 1 devices.

I

IANA

The Internet Assigned Numbers Authority (IANA). An organization that owns the rights to assign many operating numbers and facts about how the global Internet works, including public IPv4 and IPv6 addresses. *See also* ICANN.

ICANN

The Internet Corporation for Assigned Names and Numbers. An organization appointed by IANA to oversee the distributed process of assigning public IPv4 and IPv6 addresses across the globe.

ICMP

Internet Control Message Protocol. A TCP/IP network layer protocol that reports errors and provides other information relevant to IP packet processing.

IEEE

Institute of Electrical and Electronics Engineers. A professional organization that develops communications and network standards, among other activities.

IEEE 802.2

An IEEE LAN protocol that specifies an implementation of the LLC sublayer of the data link layer.

IEEE 802.3

A set of IEEE LAN protocols that specifies the many variations of what is known today as an Ethernet LAN.

IETF

The Internet Engineering Task Force. The IETF serves as the primary organization that works directly to create new TCP/IP standards.

inactivity timer

For switch MAC address tables, a timer associated with each entry that counts time upward from 0 and is reset to 0 each time a switch receives a frame with the same MAC address. The entries with the largest timers can be removed to make space for additional MAC address table entries.

inside global

For packets sent to and from a host that resides inside the trusted part of a network that uses NAT, a term referring to the IP address used in the headers of those packets when those packets traverse the global (public) Internet.

inside local

For packets sent to and from a host that resides inside the trusted part of a network that uses NAT, a term referring to the IP address used in the headers of those packets when those packets traverse the enterprise (private) part of the network.

interior gateway protocol (IGP)

See interior routing protocol.

interior routing protocol

A routing protocol designed for use within a single organization.

intrusion detection system (IDS)

A security function that examines more complex traffic patterns against a list of both known attack signatures and general characteristics of how attacks can be carried out, rating each perceived threat and reporting the threats.

intrusion prevention system (IPS)

A security function that examines more complex traffic patterns against a list of both known attack signatures and general characteristics of how attacks can be carried out, rating each perceived threat, and reacting to prevent the more significant threats.

IOS

Cisco Internetwork Operating System Software that provides the majority of a router's or switch's features, with the hardware providing the remaining features.

IOS image

A file that contains the IOS.

IP

Internet Protocol. The network layer protocol in the TCP/IP stack, providing routing and logical addressing standards and services.

IP address (IP version 4)

In IP version 4 (IPv4), a 32-bit address assigned to hosts using TCP/IP. Each address consists of a network number, an optional subnetwork number, and a host number. The network and subnetwork numbers together are used for routing, and the host number is used to address an individual host within the network or subnetwork.

IP address (IP version 6)

In IP version 6 (IPv6), a 128-bit address assigned to hosts using TCP/IP. Addresses use different formats, commonly using a routing prefix, subnet, and interface ID, corresponding to the IPv4 network, subnet, and host parts of an address.

IP network

See classful IP network.

IP packet

An IP header, followed by the data encapsulated after the IP header, but specifically not including any headers and trailers for layers below the network layer.

IP subnet

Subdivisions of a Class A, B, or C network, as configured by a network administrator. Subnets allow a single Class A, B, or C network to be used instead of multiple networks, and still allow for a large number of groups of IP addresses, as is required for efficient IP routing.

IP version 4

Literally, the version of the Internet Protocol defined in an old RFC 791, standardized in 1980, and used as the basis of TCP/IP networks and the Internet for over 30 years.

IP version 6

A newer version of the Internet Protocol defined in RFC 2460, as well as many other RFCs, whose creation was motivated by the need to avoid the IPv4 address exhaustion problem.

IPv4 address exhaustion

The process by which the public IPv4 addresses, available to create the Internet, were consumed through the 1980s until today, with the expectation that eventually the world would run out of available IPv4 addresses.

IPv6 neighbor table

The IPv6 equivalent of the ARP table. A table that lists IPv6 addresses of other hosts on the same link, along with their matching MAC addresses, as typically learned using Neighbor Discovery Protocol (NDP).

ISDN

Integrated Services Digital Network. A service offered by telephone companies that permits telephone networks to carry data, voice, and other traffic. Often used as an Internet access technology, as well as dial backup when routers lose their normal WAN communications links.

ISL

Inter-Switch Link. A Cisco-proprietary protocol that maintains VLAN information as traffic flows between switches and routers.

ISO

International Organization for Standardization. An international organization that is responsible for a wide range of standards, including many standards relevant to networking. The ISO developed the OSI reference model, a popular networking reference model.

K

keepalive

A proprietary feature of Cisco routers in which the router sends messages on a periodic basis as a means of letting the neighboring router know that the first router is still alive and well.

L

L4PDU

Layer 4 protocol data unit. The data compiled by a Layer 4 protocol, including Layer 4 headers and encapsulated high-layer data, but not including lower-layer headers and trailers.

Layer 3 protocol

A protocol that has characteristics like OSI Layer 3, which defines logical addressing and routing. IPv4 and IPv6 are Layer 3 protocols.

Layer 3 switch

See multilayer switch.

learning

The process used by switches for discovering MAC addresses, and their relative location, by looking at the source MAC address of all frames received by a bridge or switch.

leased line

A serial communications circuit between two points, provided by some service provider, typically a telephone company (telco). Because the telco does not sell a physical cable between the two endpoints, instead charging a monthly fee for the ability to send bits between the two sites, the service is considered to be a leased service.

link-local address

A type of unicast IPv6 address that represents an interface on a single data link. Packets sent to a link-local address cross only that particular link and are never forwarded to other subnets by a router. Used for communications that do not need to leave the local link.

link-local scope

With IPv6 multicasts, a term that refers to the parts (scope) of the network to which a multicast packet can flow, with link-local referring to the fact that the packet stays on the subnet in which it originated.

link-state

A classification of the underlying algorithm used in some routing protocols. Link-state protocols build a detailed database that lists links (subnets) and their state (up, down), from which the best routes can then be calculated.

link-state advertisement (LSA)

In OSPF, the name of the data structure that resides inside the LSDB and describes in detail the various components in a network, including routers and links (subnets).

link-state database (LSDB)

In OSPF, the data structure in RAM of a router that holds the various LSAs, with the collective LSAs representing the entire topology of the network.

LLC

Logical Link Control. The higher of the two data link layer sublayers defined by the IEEE. Synonymous with IEEE 802.2.

local loop

A line from the premises of a telephone subscriber to the telephone company CO.

local subnet broadcast address

IPv4 address 255.255.255.255. A packet sent to this address is sent as a data link broadcast, but only flows to hosts in the subnet into which it was originally sent. Routers do not forward these packets.

local username

A username (with matching password), configured on a router or switch. It is considered local because it exists on the router or switch, and not on a remote server.

logical address

A generic reference to addresses as defined by Layer 3 protocols that do not have to be concerned with the physical details of the underlying physical media. Used mainly to contrast these addresses with data link addresses, which are generically considered to be physical addresses because they differ based on the type of physical medium.

M

MAC

Media Access Control. The lower of the two sublayers of the data link layer defined by the IEEE. Synonymous with IEEE 802.3 for Ethernet LANs.

MAC address

A standardized data link layer address that is required for every device that connects to a LAN. Ethernet MAC addresses are 6 bytes long and are controlled by the IEEE. Also known as a *hardware address*, a *MAC layer address*, and a *physical address*.

metric

A unit of measure used by routing protocol algorithms to determine the best route for traffic to use to reach a particular destination.

microsegmentation

The process in LAN design by which every switch port connects to a single device, with no hubs connected to the switch ports, creating a separate collision domain per interface. The term's origin relates to the fact that one definition for the word "segment" is "collision domain," with a switch separating each switch port into a separate collision domain or segment.

modem

Modulator-demodulator. A device that converts between digital and analog signals so that a computer can send data to another computer using analog telephone lines. At the source, a modem converts digital signals to a form suitable for transmission over analog communication facilities. At the destination, the analog signals are returned to their digital form.

multilayer switch

A LAN switch that can also perform Layer 3 routing functions. The name comes from the fact that this device makes forwarding decisions based on logic from multiple OSI layers (Layers 2 and 3).

multimode

A type of fiber-optic cabling with a larger core than single-mode cabling, allowing light to enter at multiple angles. Such cabling has lower bandwidth than single-mode fiber but requires a typically cheaper light source, such as an LED rather than a laser.

N

name server

A server connected to a network that resolves network names into network addresses.

named access list

An ACL that identifies the various statements in the ACL based on a name, rather than a number.

NAT

Network Address Translation. A mechanism for reducing the need for globally unique IP addresses. NAT allows an organization with addresses that are not globally unique to connect to the Internet, by translating those addresses into public addresses in the globally routable address space.

neighbor

In routing protocols, another router with which a router decides to exchange routing information.

Neighbor Advertisement (NA)

A message defined by the IPv6 Neighbor Discovery Protocol (NDP), used to declare to other neighbors a host's MAC address. Sometimes sent in response to a previously received NDP Neighbor Solicitation (NS) message.

Neighbor Discovery Protocol (NDP)

A protocol that is part of the IPv6 protocol suite, used to discover and exchange information about devices on the same subnet (neighbors). In particular, it replaces the IPv4 ARP protocol.

Neighbor Solicitation (NS)

A message defined by the IPv6 Neighbor Discovery Protocol (NDP), used to ask a neighbor to reply with a Neighbor Advertisement, which lists the neighbor's MAC address.

network

A collection of computers, printers, routers, switches, and other devices that can communicate with each other over some transmission medium.

network address

See network number.

network broadcast address

In IPv4, a special address in each classful network that can be used to broadcast a packet to all hosts in that same classful network. Numerically, the address has the same value as the network number in the network part of the address and all 255s in the host octets—for example, 10.255.255.255 is the network broadcast address for classful network 10.0.0.0.

network interface card (NIC)

A computer card, sometimes an expansion card and sometimes integrated into the motherboard of the computer, that provides the electronics and other functions to connect to a computer network. Today, most NICs are specifically Ethernet NICs, and most have an RJ-45 port, the most common type of Ethernet port.

network number

A number that uses dotted-decimal notation like IP addresses, but the number itself represents all hosts in a single Class A, B, or C IP network.

network part

The portion of an IPv4 address that is either 1, 2, or 3 octets/bytes long, based on whether the address is in a Class A, B, or C network.

Network Time Protocol (NTP)

A protocol used to synchronize time-of-day clocks so that multiple devices use the same time of day, which allows log messages to be more easily matched based on their timestamps.

networking model

A generic term referring to any set of protocols and standards collected into a comprehensive grouping that, when followed by the devices in a network, allows all the devices to communicate. Examples include TCP/IP and OSI.

next-hop router

In an IP route in a routing table, part of a routing table entry that refers to the next IP router (by IP address) that should receive packets that match the route.

NIC

See network interface card.

NVRAM

Nonvolatile RAM. A type of random-access memory (RAM) that retains its contents when a unit is powered off.

O

ordered data transfer

A networking function, included in TCP, in which the protocol defines how the sending host should number the data transmitted, defines how the receiving device should attempt to reorder the data if it arrives out of order, and specifies to discard the data if it cannot be delivered in order.

OSI

Open System Interconnection reference model. A network architectural model developed by the ISO. The model consists of seven layers, each of which specifies particular network functions, such as addressing, flow control, error control, encapsulation, and reliable message transfer.

OSPF

Open Shortest Path First. A popular link-state IGP that uses a link-state database and the Shortest Path First (SPF) algorithm to calculate the best routes to reach each known subnet.

OSPF version 2

The version of the OSPF routing protocol that supports IPv4, and not IPv6, and has been commonly used for over 20 years.

OSPF version 3

The version of the OSPF routing protocol that supports IPv6, and not IPv4.

outgoing interface

In an IP route in a routing table, part of a routing table entry that refers to the local interface out which the local router should forward packets that match the route.

overlapping subnets

An (incorrect) IP subnet design condition in which one subnet's range of addresses includes addresses in the range of another subnet.

P

packet

A logical grouping of bytes that includes the network layer header and encapsulated data, but specifically does not include any headers and trailers below the network layer.

packet switching

A generic reference to network services, typically WAN services, in which the service examines the contents of the transmitted data to make some type of forwarding decision. This term is mainly used to contrast with the WAN term *circuit switching*, in which the provider sets up a (Layer 1) circuit between two devices and the provider makes no attempt to interpret the meaning of the bits.

partial mesh

A network topology in which more than two devices could physically communicate but, by choice, only a subset of the pairs of devices connected to the network is allowed to communicate directly.

patch cable

An Ethernet cable, usually short, that connects from a device's Ethernet port to a wall plate or switch. With wiring inside a building, electricians prewire from the wiring closet to each cubicle or other location, with a patch cable connecting the short distance from the wall plate to the user device.

PDU

Protocol data unit. An OSI term to refer generically to a grouping of information by a particular layer of the OSI model. More specifically, an L*x*PDU would imply the data and headers as defined by Layer *x*.

ping

An Internet Control Message Protocol (ICMP) echo message and its reply; ping often is used in IP networks to test the reachability of a network device.

pinout

The documentation and implementation of which wires inside a cable connect to each pin position in any connector.

port

In TCP and UDP, a number that is used to uniquely identify the application process that either sent (source port) or should receive (destination port) data. In LAN switching, another term for switch interface.

Port Address Translation (PAT)

A NAT feature in which one inside global IP address supports over 65,000 concurrent TCP and UDP connections.

port number

A field in a TCP or UDP header that identifies the application that either sent (source port) or should receive (destination port) the data inside the data segment.

port security

A Cisco switch feature in which the switch watches Ethernet frames that come in an interface (a port), tracks the source MAC addresses of all such frames, and takes a security action if the number of different such MAC addresses is exceeded.

PPP

Point-to-Point Protocol. A protocol that provides router-to-router and host-to-network connections over synchronous point-to-point and asynchronous point-to-point circuits.

prefix

In IPv6, this term refers to the number that identifies a group of IPv6 addresses. An IPv6 subnet identifier.

prefix length

In IPv6, the number of bits in an IPv6 prefix.

prefix notation (IP version 4)

A shorter way to write a subnet mask in which the number of binary 1s in the mask is simply written in decimal. For example, /24 denotes the subnet mask with 24 binary 1 bits in the subnet mask. The number of bits of value binary 1 in the mask is considered to be the prefix length.

private addresses

IP addresses in several Class A, B, and C networks that are set aside for use inside private organizations. These addresses, as defined in RFC 1918, are not routable through the Internet.

problem isolation

The part of the troubleshooting process in which the engineer attempts to rule out possible causes of the problem until the root cause of the problem can be identified.

protocol data unit (PDU)

A generic term referring to the header defined by some layer of a networking model, and the data encapsulated by the header (and possibly trailer) of that layer, but specifically not including any lower-layer headers and trailers.

Protocol Type field

A field in a LAN header that identifies the type of header that follows the LAN header. Includes the DIX Ethernet Type field, the IEEE 802.2 DSAP field, and the SNAP protocol Type field.

PSTN

Public switched telephone network. A general term referring to the variety of telephone networks and services in place worldwide. Sometimes called *POTS*, or *plain old telephone service*.

PTT

Post, telephone, and telegraph. A government agency that provides telephone services. PTTs exist in some areas outside of North America and provide both local and long-distance telephone services.

public IP address

An IP address that is part of a registered network number, as assigned by an Internet Assigned Numbers Authority (IANA) member agency, so that only the organization to which the address is registered is allowed to use the address. Routers in the Internet should have routes allowing them to forward packets to all the publicly registered IP addresses.

Q

quartet

A term used in this book, but not in other references, to refer to a set of four hex digits in an IPv6 address.

R

RAM

Random-access memory. A type of volatile memory that can be read and written by a microprocessor.

RFC

Request For Comments. A document used as the primary means for communicating information about the TCP/IP protocols. Some RFCs are designated by the Internet Architecture Board (IAB) as Internet standards, and others are informational. RFCs are available online from numerous sources, including www.rfc-editor.org.

RIP

Routing Information Protocol. An interior gateway protocol (IGP) that uses distance vector logic and router hop count as the metric. RIP version 2 (RIP-2) replaced the older RIP version 1 (RIP-1), with RIP-2 providing more features, including support for VLSM.

RJ-45

A popular type of cabling connector used for Ethernet cabling. It is similar to the RJ-11 connector used for telephone wiring in homes in the United States. RJ-45 allows the connection of eight wires.

ROM

Read-only memory. A type of nonvolatile memory that can be read but not written to by the microprocessor.

root cause

A troubleshooting term that refers to the reason why a problem exists, specifically a reason for which, if changed, the problem would either be solved or changed to a different problem.

routed protocol

A protocol that defines packets that can be routed by a router. Examples of routed protocols include IPv4 and IPv6.

Router Advertisement (RA)

A message defined by the IPv6 Neighbor Discovery Protocol (NDP), used by routers to announce their willingness to act as an IPv6 router on a link. These can be sent in response to a previously received NDP Router Solicitation (RS) message.

router ID (RID)

In OSPF, a 32-bit number, written in dotted-decimal notation, that uniquely identifies each router.

Router Solicitation (RS)

A message defined by the IPv6 Neighbor Discovery Protocol (NDP), used to ask any routers on the link to reply, identifying the router, plus other configuration settings (prefixes and prefix lengths).

routing protocol

A set of messages and processes with which routers can exchange information about routes to reach subnets in a particular network. Examples of routing protocols include the Enhanced Interior Gateway Routing Protocol (EIGRP), the Open Shortest Path First (OSPF) protocol, and the Routing Information Protocol (RIP).

routing table

A list of routes in a router, with each route listing the destination subnet and mask, the router interface out which to forward packets destined to that subnet, and as needed, the next-hop router's IP address.

routing update

A generic reference to any routing protocol's messages in which it sends routing information to a neighbor.

running-config file

In Cisco IOS switches and routers, the name of the file that resides in RAM memory, holding the device's currently used configuration.

S

same-layer interaction

The communication between two networking devices for the purposes of the functions defined at a particular layer of a networking model, with that communication happening by using a header defined by that layer of the model. The two devices set values in the header, send the header and encapsulated data, with the receiving device(s) interpreting the header to decide what action to take.

Secure Shell (SSH)

A TCP/IP application layer protocol that supports terminal emulation between a client and server, using dynamic key exchange and encryption to keep the communications private.

segment

In TCP, a term used to describe a TCP header and its encapsulated data (also called an *L4PDU*). Also in TCP, the process of accepting a large chunk of data from the application layer and breaking it into smaller pieces that fit into TCP segments. In Ethernet, a segment is either a single Ethernet cable or a single collision domain (no matter how many cables are used).

segmentation

The process of breaking a large piece of data from an application into pieces appropriate in size to be sent through the network.

serial cable

A type of cable with many different styles of connectors used to connect a router to an external CSU/DSU on a leased-line installation.

serial interface

A type of interface on a router, used to connect to some types of WAN links, particularly leased lines and Frame Relay access links.

setup mode

An option on Cisco IOS switches and routers that prompts the user for basic configuration information, resulting in new running-config and startup-config files.

shared Ethernet

An Ethernet that uses a hub, or even the original coaxial cabling, that results in the devices having to take turns sending data, sharing the available bandwidth.

Shortest Path First (SPF) algorithm

The name of the algorithm used by link-state routing protocols to analyze the LSDB and find the least-cost routes from that router to each subnet.

single-mode

A type of fiber-optic cabling with a narrow core that allows light to enter only at a single angle. Such cabling has a higher bandwidth than multimode fiber but requires a light source with a narrow spectral width (such as a laser).

sliding windows

For protocols such as TCP that allow the receiving device to dictate the amount of data the sender can send before receiving an acknowledgment—a concept called a *window*—a reference to the fact that the mechanism to grant future windows is typically just a number that grows upward slowly after each acknowledgment, sliding upward.

solicited-node multicast address

A type of IPv6 multicast address, with link-local scope, used to send packets to all hosts in the subnet that share the same value in the last six hex digits of their unicast IPv6 addresses. Begins with FF02::1:FF00:0/104.

SONET

Synchronous Optical Network. A standard format for transporting a wide range of digital telecommunications services over optical fiber.

Spanning Tree Protocol (STP)

A protocol that uses the Spanning Tree algorithm, allowing a switch to dynamically work around loops in a network topology by creating a spanning tree. Switches exchange bridge protocol data unit (BPDU) messages with other switches to detect loops and then remove the loops by blocking selected switch interfaces.

standard access list

A list of IOS global configuration commands that can match only a packet's source IP address, for the purpose of deciding which packets to discard and which to allow through the router.

star

A network topology in which endpoints on a network are connected to a common central device by point-to-point links.

startup-config file

In Cisco IOS switches and routers, the name of the file that resides in NVRAM memory, holding the device's configuration that will be loaded into RAM as the running-config file when the device is next reloaded or powered on.

stateful DHCP

A term used in IPv6 to contrast with stateless DHCP. Stateful DHCP keeps track of which clients have been assigned which IPv6 addresses (state information).

Stateless Address Autoconfiguration (SLAAC)

A feature of IPv6 in which a host or router can be assigned an IPv6 unicast address without the need for a stateful DHCP server.

stateless DHCP

A term used in IPv6 to contrast with stateful DHCP. Stateless DHCP servers don't lease IPv6 addresses to clients. Instead, they supply other useful information, such as DNS server IP addresses, but with no need to track information about the clients (state information).

static route

An IP route on a router created by the user configuring the details of the route on the local router.

store-and-forward switching

One of three internal processing options on some Cisco LAN switches in which the Ethernet frame must be completely received before the switch can begin forwarding the first bit of the frame.

STP

Shielded twisted-pair. This type of cabling has a layer of shielded insulation to reduce electromagnetic interference (EMI).

straight-through cable

In Ethernet, a cable that connects the wire on pin 1 on one end of the cable to pin 1 on the other end of the cable, pin 2 on one end to pin 2 on the other end, and so on.

subnet

Subdivisions of a Class A, B, or C network, as configured by a network administrator. Subnets allow a single Class A, B, or C network to be used instead of multiple networks, and still allow for a large number of groups of IP addresses, as is required for efficient IP routing.

subnet address

See subnet number.

subnet broadcast address

A special address in each subnet, specifically the largest numeric address in the subnet, designed so that packets sent to this address should be delivered to all hosts in that subnet.

subnet ID (IPv4)

See subnet number.

subnet ID (IPv6)

The number that represents the IPv6 subnet. Also known as the IPv6 prefix, or more formally as the subnet router anycast address.

subnet mask

A 32-bit number that numerically describes the format of an IP address, by representing the combined network and subnet bits in the address with mask bit values of 1, and representing the host bits in the address with mask bit values of 0.

subnet number

In IPv4, a dotted-decimal number that represents all addresses in a single subnet. Numerically, the smallest value in the range of numbers in a subnet, reserved so that it cannot be used as a unicast IP address by a host.

subnet part

In a subnetted IPv4 address, interpreted with classful addressing rules, one of three parts of the structure of an IP address, with the subnet part uniquely identifying different subnets of a classful IP network.

subnetting

The process of subdividing a Class A, B, or C network into smaller groups called subnets.

switch

A network device that filters, forwards, and floods Ethernet frames based on the destination address of each frame.

switched Ethernet

An Ethernet that uses a switch, and particularly not a hub, so that the devices connected to one switch port do not have to contend to use the bandwidth available on another port. This term contrasts with *shared Ethernet*, in which the devices must share bandwidth, whereas switched Ethernet provides much more capacity, as the devices do not have to share the available bandwidth.

symmetric

A feature of many Internet access technologies in which the downstream transmission rate is the same as the upstream transmission rate.

synchronous

The imposition of time ordering on a bit stream. Practically, a device will try to use the same speed as another device on the other end of a serial link. However, by examining transitions between voltage states on the link, the device can notice slight variations in the speed on each end and can adjust its speed accordingly.

T

T1

A line from the telco that allows transmission of data at 1.544 Mbps, with the ability to treat the line as 24 different 64-kbps DS0 channels (plus 8 kbps of overhead).

TCP

Transmission Control Protocol. A connection-oriented transport layer TCP/IP protocol that provides reliable data transmission.

TCP/IP

Transmission Control Protocol/Internet Protocol. A common name for the suite of protocols developed by the U.S. Department of Defense in the 1970s to support the construction of worldwide internetworks. TCP and IP are the two best-known protocols in the suite.

telco

A common abbreviation for telephone company.

Telnet

The standard terminal-emulation application layer protocol in the TCP/IP protocol stack. Telnet is used for remote terminal connection, enabling users to log in to remote systems and use resources as if they were connected to a local system. Telnet is defined in RFC 854.

trace

Short for traceroute. A program available on many systems that traces the path that a packet takes to a destination. It is used mostly to troubleshoot routing problems between hosts.

trailer

In computer networking, a set of bytes placed behind some other data, encapsulating that data, as defined by a particular protocol. Typically, only data link layer protocols define trailers.

transparent bridge

The name of a networking device that was a precursor to modern LAN switches. Bridges forward frames between LAN segments based on the destination MAC address. Transparent bridging is so named because the presence of bridges is transparent to network end nodes.

trunk

In campus LANs, an Ethernet segment over which the devices add a VLAN header that identifies the VLAN in which the frame exists.

trunk interface

A switch interface configured so that it operates using VLAN trunking (either 802.1Q or ISL).

trunking

Also called VLAN trunking. A method (using either the Cisco ISL protocol or the IEEE 802.1Q protocol) to support multiple VLANs, allowing traffic from those VLANs to cross a single link.

trunking administrative mode

The configured trunking setting on a Cisco switch interface, as configured with the **switchport mode** command.

trunking operational mode

The current behavior of a Cisco switch interface for VLAN trunking.

twisted-pair

Transmission medium consisting of two insulated wires, with the wires twisted around each other in a spiral. An electrical circuit flows over the wire pair, with the current in opposite directions on each wire, which significantly reduces the interference between the two wires.

U

UDP

User Datagram Protocol. Connectionless transport layer protocol in the TCP/IP protocol stack. UDP is a simple protocol that exchanges datagrams without acknowledgments or guaranteed delivery.

unicast address

Generally, any address in networking that represents a single device or interface, instead of a group of addresses (as would be represented by a multicast or broadcast address).

unicast IP address

An IP address that represents a single interface. In IPv4, these addresses come from the Class A, B, and C ranges.

unique local address

A type of IPv6 unicast address meant as a replacement for IPv4 private addresses.

unknown unicast frame

An Ethernet frame whose destination MAC address is not listed in a switch’s MAC address table, so the switch must flood the frame.

up and up

Jargon referring to the two interface states on a Cisco IOS router or switch (line status and protocol status), with the first “up” referring to the line status and the second “up” referring to the protocol status. An interface in this state should be able to pass data link frames.

update timer

A timer used by a router to indicate when to send the next routing update.

URL

Uniform Resource Locator. A standard for how to refer to any piece of information retrievable via a TCP/IP network, most notably used to identify web pages. For example, http://www.certskills.com/blog is a URL that identifies the protocol (HTTP), host name (www.certskills.com), and web page (blog).

user mode

A mode of the user interface to a router or switch in which the user can type only nondisruptive EXEC commands, generally just to look at the current status, but not to change any operational settings.

UTP

Unshielded twisted-pair. A type of cabling, standardized by the Telecommunications Industry Association (TIA), that holds twisted pairs of copper wires (typically four pair) and does not contain any shielding from outside interference.

V

variable-length subnet mask (VLSM)

The capability to specify a different subnet mask for the same Class A, B, or C network number on different subnets. VLSM can help optimize available address space.

virtual circuit (VC)

In packet-switched services like Frame Relay, VC refers to the ability of two DTE devices (typically routers) to send and receive data directly to each other, which supplies the same function as a physical leased line (leased circuit), but doing so without a physical circuit. This term is meant as a contrast with a leased line or leased circuit.

virtual LAN (VLAN)

A group of devices, connected to one or more switches, with the devices grouped into a single broadcast domain through switch configuration. VLANs allow switch administrators to separate the devices connected to the switches into separate

VLANs without requiring separate physical switches, gaining design advantages of separating the traffic without the expense of buying additional hardware.

Virtual Private Network (VPN)

The process of securing communication between two devices whose packets pass over some public and unsecured network, typically the Internet. VPNs encrypt packets so that the communication is private, and authenticate the identity of the endpoints.

VLAN

See virtual LAN.

VLAN configuration database

The name of the collective configuration of VLAN IDs and names on a Cisco switch.

VLAN interface

A configuration concept inside Cisco switches, used as an interface between IOS running on the switch and a VLAN supported inside the switch, so that the switch can assign an IP address and send IP packets into that VLAN.

VLAN Trunking Protocol (VTP)

A Cisco-proprietary messaging protocol used between Cisco switches to communicate configuration information about the existence of VLANs, including the VLAN ID and VLAN name.

vlan.dat

The default file used to store a Cisco switch's VLAN configuration database.

VoIP

Voice over IP. The transport of voice traffic inside IP packets over an IP network.

VTP

See VLAN Trunking Protocol.

VTP client mode

One of three VTP operational modes for a switch with which switches learn about VLAN numbers and names from other switches, but which does not allow the switch to be directly configured with VLAN information.

VTP server mode

One of three VTP operational modes. Switches in server mode can configure VLANs, tell other switches about the changes, and learn about VLAN changes from other switches.

VTP transparent mode

One of three VTP operational modes. Switches in transparent mode can configure VLANs, but they do not tell other switches about the changes, and they do not learn about VLAN changes from other switches.

W

web server

Software, running on a computer, that stores web pages and sends those web pages to web clients (web browsers) that request the web pages.

well-known port

A TCP or UDP port number reserved for use by a particular application. The use of well-known ports allows a client to send a TCP or UDP segment to a server, to the correct destination port for that application.

Wi-Fi Alliance

An organization formed by many companies in the wireless industry (an industry association) for the purpose of getting multivendor certified-compatible wireless products to market in a more timely fashion than would be possible by simply relying on standardization processes.

wide-area network (WAN)

A part of a larger network that implements mostly OSI Layer 1 and 2 technology, connects sites that typically sit far apart, and uses a business model in which a consumer (individual or business) must lease the WAN from a service provider (often a telco).

wildcard mask

The mask used in Cisco IOS ACL commands and OSPF and EIGRP **network** commands.

window

Represents the number of bytes that can be sent without receiving an acknowledgment.

wireless LAN

A local-area network (LAN) that physically transmits bits using radio waves. The name "wireless" compares these LANs to more traditional "wired" LANs, which are LANs that use cables (which often have copper wires inside).

WLAN client

A wireless device that wants to gain access to a wireless access point for the purpose of communicating with other wireless devices or other devices connected to the wired internetwork.

Z

zero subnet

For every classful IPv4 network that is subnetted, the one subnet whose subnet number has all binary 0s in the subnet part of the number. In decimal, the zero subnet can be easily identified because it is the same number as the classful network number.

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DVD-only Appendixes

Appendix C. Answers to the "Do I Know This Already?" Quizzes

Chapter 1

1. D and F. Of the remaining answers, Ethernet defines both physical and data link protocols, PPP is a data link protocol, IP is a network layer protocol, and SMTP and HTTP are application layer protocols.
2. A and G. Of the remaining answers, IP is a network layer protocol, TCP and UDP are transport layer protocols, and SMTP and HTTP are application layer protocols.
3. B. Adjacent-layer interaction occurs on one computer, with two adjacent layers in the model. The higher layer requests services from the next lower layer, and the lower layer provides the services to the next higher layer.
4. B. Same-layer interaction occurs on multiple computers. The functions defined by that layer typically need to be accomplished by multiple computers—for example, the sender setting a sequence number for a segment, and the receiver acknowledging receipt of that segment. A single layer defines that process, but the implementation of that layer on multiple devices is required to accomplish the function.
5. A. Encapsulation is defined as the process of adding a header in front of data supplied by a higher layer (and possibly adding a trailer as well).
6. D. By convention, the term *frame* refers to the part of a network message that includes the data link header and trailer, with encapsulated data. The term *packet* omits the data link header and trailer, leaving the network layer header with its encapsulated data. The term *segment* omits the network layer header, leaving the transport layer header and its encapsulated data.
7. C. The network layer concerns itself with delivery of data over the complete end-to-end path. That requires a way to identify each device, using addresses, and the addresses must be logical addresses that are therefore not tied to the physical details of the network.
8. A. The OSI physical layer includes all standards that specify the shape of connectors, wiring in cabling, electrical details, and encoding that the electrical signals use to encode bits over a cable.
9. C and E. The layer names, from top to bottom, are application, presentation, session, transport, network, data link, and physical.

Chapter 2

1. A. The IEEE defines Ethernet LAN standards, with standard names that begin with 802.3, all of which happen to use cabling. The IEEE also defines wireless LAN standards, with standard names that begin with 802.11, which are separate standards from Ethernet.
2. C. The number before the word "BASE" defines the speed, in megabits per second (Mbps). 1000 Mbps equals 1 gigabit per second (1 Gbps). The "T" in the suffix implies twisted-pair or UTP cabling, so 1000BASE-T is the UTP-based Gigabit Ethernet standard name.
3. B. Crossover cables cross the wire at one node's transmit pin pair to the different pins used as the receive pins on the other device. For 10-and 100-Mbps Ethernet, the specific crossover cable wiring connects the pair at pins 1 and 2 on each end of the cable to pins 3 and 6 on the other end of the cable, respectively.
4. B, D, and E. Routers, wireless access point Ethernet ports, and PC NICs all send using pins 1 and 2, whereas hubs and LAN switches transmit on pins 3 and 6. Straight-through cables connect devices that use opposite pin pairs for sending, because the cable does not need to cross the pairs.
5. B. NICs (and switch ports) use the carrier sense multiple access with collision detection (CSMA/CD) algorithm to implement half-duplex logic. While CSMA/CD attempts to avoid collisions, it also notices when collisions do occur, with rules about how the Ethernet nodes should stop sending, wait, and try again later.
6. C. The 4-byte Ethernet FCS field, found in the Ethernet trailer, allows the receiving node to see what the sending node computed with a math formula that is a key part of the error-detection process. Note that Ethernet defines the process of detecting errors (error detection), but not error recovery.
7. B, C, and E. The preassigned universal MAC address, given to each Ethernet port when manufactured, breaks the address into two 3-byte halves. The first half is called the organizationally unique identifier (OUI), which the IEEE assigns to the company that builds the product as a unique hex number to be used only by that company.
8. C and D. Ethernet supports unicast addresses, which identify a single Ethernet node, and group addresses, which can be used to send one frame to multiple Ethernet nodes. The two types of group addresses are the *broadcast address* and *multicast addresses*.

Chapter 3

1. B. OSI Layer 1, the physical layer, defines how to physically transmit bits using some kind of physical medium, like a cable or radio waves. OSI Layer 2, the data link layer, defines protocols that control and manage the transmission, including the definition of data link frames, which include addresses, and fields to help perform error detection.
2. B. The four-wire circuit cable supplied by the telco connects to the device acting as the CSU/DSU. That can be an external CSU/DSU or a CSU/DSU integrated into a router serial interface card. LAN switches do not have serial interfaces, and router serial interfaces do not have transceivers.
3. C. Leased lines can run at various preset speeds. These include multiples of 64 kbps, up through 24 times 64 kbps. The speeds can also be multiples of T1 speed (1.544 Mbps), up to 28 times that speed.
4. B. The standard HDLC header does not include a Type field, which identifies the type of packet encapsulated inside the

HDLC frame.

5. B and D. The physical installation uses a model in which each router uses a physical Ethernet link to connect to some SP device in an SP facility called a point of presence (POP). The Ethernet link does not span from each customer device to the other. From a data link perspective, both routers use the same Ethernet standard header and trailer used on LANs; HDLC does not matter on these Ethernet WAN links.
6. B and C. Leased lines transmit data at the same speed in both directions, making it a symmetric service. DSL and cable Internet offer asymmetric speeds, with a faster downstream speed. BGP is a routing protocol and is not an Internet access technology.
7. C. With DSL, the requirements on the phone's wiring are unchanged. The phone can connect to any working telephone jack, as if the DSL modem and router did not exist.

Chapter 4

1. A and C. The network layer defines logical addressing, in contrast to physical addressing. The logical address structure allows easy grouping of addresses, which makes routing more efficient. Path selection refers to the process of choosing the best routes to use in the network. Physical addressing and arbitration typically are data link layer functions, and error recovery typically is a transport layer function.
2. C and E. Because PC1 and PC2 are separated by routers, the PCs must rely on the routers to use routing logic. With routing, the router discards the data link header of an incoming frame, making a decision of where to forward the packet deencapsulated from the frame. As a result, the largest entity that passes from PC1 to PC2 is the IPv4 packet (or IPv6 packet), which goes by the more general name of L3PDU.
3. B. 224.1.1.1 is a Class D address. 223.223.223.255 is the network broadcast address for Class C network 223.223.223.0, so it cannot be assigned to a host.
4. D. The first octet of Class A addresses ranges from 1 to 126, inclusive; Class B, 128 to 191, inclusive; and Class C, 192 to 223 inclusive. 127 is technically in the Class A range, but it is a reserved address used as a loopback.
5. D and F. Without any subnetting in use, all addresses in the same network as 10.1.1.1—all addresses in Class A network 10.0.0.0—must be on the same LAN. Addresses separated from that network by some router cannot be in network 10.0.0.0. So, the two correct answers are the only two answers that list a valid unicast IP address that is not in network 10.0.0.0.
6. A. PC1 will send an Ethernet frame to Router1, with PC1's MAC address as the source address and Router1's MAC address as the destination address. Router1 will remove the encapsulated IP packet from that Ethernet frame, discarding the frame header and trailer. Router1 will forward the IP packet by first encapsulating it inside an HDLC frame, but Router1 will not encapsulate the Ethernet frame in the HDLC frame, but rather the IP packet. Router2 will deencapsulate the IP packet from the HDLC frame and forward it onto the Ethernet LAN, adding a new Ethernet header and trailer, but this header will differ. It will list Router2's MAC address as the source address and PC2's MAC address as the destination address.
7. C. Routers compare the packet's destination IP address to the router's IP routing table, making a match and using the forwarding instructions in the matched route to forward the IP packet.
8. B and C. IPv4 hosts generally use basic two-branch logic. To send an IP packet to another host on the same IP network or subnet that is on the same LAN, the sender sends the IP packet directly to that host. Otherwise, the sender sends the packet to its default router (also called the default gateway).
9. A and C. Routers do all the actions listed in all four answers. However, the routing protocol does the functions in the two listed answers. Independent of the routing protocol, a router learns routes for IP subnets and IP networks directly connected to its interfaces. Routers also forward (route) IP packets, but that process is called IP routing, or IP forwarding, and is an independent process compared to the work of a routing protocol.
10. C. Address Resolution Protocol (ARP) does allow PC1 to learn information, but the information is not stored on a server. The **ping** command does let the user at PC1 learn whether packets can flow in the network, but it again does not use a server. With the Domain Name System (DNS), PC1 acts as a DNS client, relying on a DNS server to respond with information about the IP addresses that match a given host name.

Chapter 5

1. D. Three of the answers define functions of TCP: error recovery, flow control, and segmentation. The correct answer defines a function not done by TCP nor UDP, but instead done by application layer protocols.
2. D and E. Many headers include a field that identifies the next header that follows inside a message. Ethernet uses the Ethernet Type field, and the IP header uses the Protocol field. The TCP and UDP headers identify the application that should receive the data that follows the TCP or UDP header by using the port number field in the TCP and UDP headers, respectively.
3. A, B, C, and F. IP, not TCP, defines routing. Many other protocols define encryption, but TCP does not. The correct answers simply list various TCP features.
4. C. TCP, not UDP, performs windowing, error recovery, and ordered data transfer. Neither performs routing or encryption.
5. C and F. The terms *packet* and *L3PDU* refer to the header plus data encapsulated by Layer 3. *Frame* and *L2PDU* refer to the header (and trailer), plus the data encapsulated by Layer 2. *Segment* and *L4PDU* refer to header and data encapsulated by the transport layer protocol.
6. B. Note that the host name is all the text between the // and the *. The text before the* / identifies the application layer protocol, and the text after the / represents the name of the web page.
7. A and D. VoIP flows need better delay, jitter, and loss, with better meaning less delay, jitter, and loss, as compared

with all data applications. VoIP typically requires less bandwidth than data applications.

Chapter 6

1. A. A switch compares the destination address to the MAC address table. If a matching entry is found, the switch knows out which interface to forward the frame. If no matching entry is found, the switch floods the frame.
2. C. A switch floods broadcast frames, multicast frames (if no multicast optimizations are enabled), and unknown unicast destination frames (frames whose destination MAC address is not in the MAC address table).
3. A. A switch floods broadcast frames, multicast frames (if no multicast optimizations are enabled), and unknown unicast destination frames (frames whose destination MAC address is not in the MAC address table).
4. B. Switches need to learn the location of each MAC address used in the LAN relative to that local switch. When a switch sends a frame, the source MAC identifies the sender. The interface in which the frame arrives identifies the local switch interface closest to that node in the LAN topology.
5. A and B. When the frame sent by PC3 arrives at the switch, the switch has learned a MAC address table entry for only 1111.1111.1111, PC1's MAC address. PC3's frame, addressed to 2222.2222.2222, is flooded, which means it is forwarded out all interfaces except for the interface on which the frame arrived.
6. A. A collision domain contains all devices whose frames could collide with frames sent by all the other devices in the domain. Bridges, switches, and routers separate or segment a LAN into multiple collision domains, whereas hubs and repeaters do not.
7. A, B, and C. A broadcast domain contains all devices whose sent broadcast frames should be delivered to all the other devices in the domain. Hubs, repeaters, bridges, and switches do not separate or segment a LAN into multiple broadcast domains, whereas routers do.
8. B and D. The IEEE Ethernet standards support 100-meter links when using UTP cabling. Most standards that use fiber-optic cabling, like the standards in the two correct answers, use lengths longer than 100 meters.
9. D. Full-duplex can be used on any Ethernet link between a switch and a PC. The IEEE autonegotiation process states that the two endpoints on a link should choose the best speed and the best duplex that both support, with full-duplex being better than half-duplex.

Chapter 7

1. A and B. The command in the question is an EXEC command that happens to require only user mode access. As an EXEC command, you cannot use the command in configuration mode, unless you preface the command with "do" (for example, **do show mac address-table**). As such, you can use this command in both user mode and enable mode.
2. B. The command referenced in the question, the **reload** command, is an EXEC command that happens to require privileged mode, also known as enable mode. As an EXEC command, you cannot use the command in configuration mode, unless you preface the command with **do** (for example, **do reload**). This command is not available in user mode.
3. B. SSH provides a secure remote login option, encrypting all data flows, including password exchanges. Telnet sends all data (including passwords) as clear text.
4. A. Switches (and routers) keep the currently used configuration in RAM, using NVRAM to store the configuration file that is loaded when the switch (or router) next loads the IOS.
5. F. The startup config file is in NVRAM, and the running config file is in RAM.
6. B and C. The **exit** command moves the user one config mode backward, toward global configuration mode, or if already in global configuration mode, it moves the user back to enable mode. From console mode, it moves the user back to global configuration mode. The **end** command and the Ctrl-Z key sequence both move the user back to enable mode regardless of the current configuration submode.

Chapter 8

1. B. If both commands are configured, IOS accepts only the password as configured in the **enable secret** command.
2. B and C. SSH requires the use of usernames in addition to a password. Using the **username** global command would be one way to define usernames (and matching passwords) to support SSH. The vty lines would also need to be configured to require the use of usernames, with the **login local** vty subcommand being one such option. The **transport input ssh** command could be part of a meaningful configuration, but it is not a global configuration command (as claimed in one wrong answer). Likewise, one answer refers to the **username** command as a command in vty config mode, which is also the wrong mode.
3. B. The first nonblank character after the **banner login** phrase is interpreted as the beginning delimiter character. In this case, it's the letter *t*. So, the second letter *t*—the first letter in "the"—is interpreted as the ending delimiter. The resulting login banner is the text between these two *t*s—namely, "his is."
4. B. The setting for the maximum number of MAC addresses has a default of 1, so the **switchport port-security maximum** command does not have to be configured. With sticky learning, you do not need to predefine the specific MAC addresses either. However, you must enable port security, which requires the **switchport port-security** interface subcommand.
5. A, D, and F. To allow access through Telnet, the switch must have password security enabled, at a minimum using the **password** vty line configuration subcommand. Additionally, the switch needs an IP address (configured under one VLAN interface) and a default gateway when the switch needs to communicate with hosts in a different subnet.
6. F. Cisco switches do not have a command to disable autonegotiation of speed and duplex. Instead, a switch port that has both **speed** and **duplex** configured disables autonegotiation.

7. E. Cisco switches can be configured for speed (with the **speed** command) and duplex (with the **duplex** command) in interface configuration mode.

Chapter 9

1. B. A VLAN is a set of devices in the same Layer 2 broadcast domain. A subnet often includes the exact same set of devices, but it is a Layer 3 concept. A collision domain refers to a set of Ethernet devices, but with different rules than VLAN rules for determining which devices are in the same collision domain.
2. D. Although a subnet and a VLAN are not equivalent concepts, the devices in one VLAN are typically in the same IP subnet and vice versa.
3. B. 802.1Q defines a 4-byte header, inserted after the original frame's destination and source MAC address fields. The insertion of this header does not change the original frame's source or destination address. The header itself holds a 12-bit VLAN ID field, which identifies the VLAN associated with the frame.
4. A. 802.1Q defines the native VLAN as one designated VLAN on a trunk for which the devices choose to not add an 802.1Q header for frames in that VLAN. The switches can set the native VLAN to any VLAN ID, but the switches should agree. The default native VLAN is VLAN 1. Note that only one such native VLAN is allowed on any one trunk; otherwise, that VLAN associated with untagged frames could not be discerned by the receiving switch.
5. A and C. The **dynamic auto** setting means that the switch can negotiate trunking, but it can only respond to negotiation messages, and it cannot initiate the negotiation process. So, the other switch must be configured to trunk or to initiate the negotiation process (based on being configured with the **dynamic desirable** option).
6. A and B. The default VTP setting of VTP transparent mode means that the switch can configure VLANs, so the VLAN is configured. Additionally, the VLAN configuration details, including the VLAN name, show up as part of the running-config file.
7. B and C. The **show interfaces switchport** command lists both the administrative and operational status of each port. When a switch considers a port to be trunking, this command lists an operational trunking state of "trunk." The **show interfaces trunk** command lists a set of interfaces: the interfaces that are currently operating as trunks. So, both these commands identify interfaces that are operational trunks.

Chapter 10

1. E and F. CDP discovers information about neighbors. **show cdp** gives you several options that display more or less information, depending on the parameters used.
2. E and F. The **show cdp neighbors** command lists one line of output per neighbor. However, it does list the platform information of the neighbor, which typically includes the hardware model number. The **show cdp entry Hannah** command lists a group of messages about the neighboring router, including more detail about the hardware model and the IOS version.
3. A, B, and D. The disabled state in the **show interfaces status** command is the same as an "administratively down and down" state shown in the **show interfaces** command. The interface must be in a connected state (per the **show interfaces status** command) before the switch can send frames out the interface.
4. A and D. SW2 has effectively disabled IEEE standard autonegotiation by configuring both speed and duplex. However, Cisco switches can detect the speed used by the other device, even with autonegotiation turned off. Also, at 1 Gbps, the IEEE autonegotiation standard says to use full-duplex if the duplex setting cannot be negotiated, so both ends use 1 Gbps, full-duplex.
5. B and D. The **show interfaces** command lists the actual speed and duplex setting, but it does not imply anything about how the settings were configured or negotiated. The **show interfaces status** command lists a prefix of **a-** in front of the speed and duplex setting to imply that the setting was autonegotiated, leaving off this prefix if the setting was configured.
6. B and C. IOS adds MAC addresses configured by the port security feature as static MAC addresses, so they do not show up in the output of the **show mac address-table dynamic** command. **show mac address-table port-security** is not a valid command.
7. A and C. The **show mac address-table** command lists all entries in the switch's MAC address table, including dynamically learned and statically defined addresses. From left to right, the output lists the VLAN ID, the MAC address, the type (static or dynamic), and the associated ports (out which frames sent to the listed address will be forwarded by this switch).
8. D. The **show interface switchport** command lists a switch's configured value of the **switchport mode** command as the administrative mode, telling us that SW1 uses the **switchport mode trunk** configuration command. The operation state shows the current working state (trunk). Of the four answers, one incorrect answer claims that SW2's operational state must also be "trunk"; however, one switch can use trunking, while the other does not. Another answer claims that the administrative mode must be "trunk," which basically means that the command **switchport mode trunk** must be used. However, SW2 has a few other configuration options that would work, like the **switchport mode dynamic desirable** and **switchport mode dynamic auto** commands. The correct answer refers to one of these commands that would work correctly.

Chapter 11

1. A and D. The general rule to determine whether two devices' interfaces should be in the same subnet is whether the two interfaces are separated from each other by a router. To provide a way for hosts in one VLAN to send data to hosts outside that VLAN, a local router must connect its LAN interface to the same VLAN as the hosts, and have an address in the same subnet as the hosts. All the hosts in that same VLAN on the same switch would not be separated

from each other by a router, so these hosts would also be in the same subnet. However, another PC, connected to the same switch but in a different VLAN, will require its packets to flow through a router to reach Host A, so Host A's IP address would need to be in a different subnet compared to this new host.

2. D. By definition, two address values in every IPv4 subnet cannot be used as host IPv4 addresses: the first (lowest) numeric value in the subnet for the subnet ID, and the last (highest) numeric value in the subnet for the subnet broadcast address.
3. B and C. At least 7 subnet bits are needed, because $2^6 = 64$, so 6 subnet bits could not number 100 different subnets. Seven subnet bits could, because $2^7 = 128 => 100$. Similarly, 6 host bits is not enough, because $2^6 - 2 = 62$, but 7 host bits is enough, because $2^7 - 2 = 126 => 100$.

   The number of network, subnet, and host bits must total 32 bits, making one of the answers incorrect. The answer with 8 network bits cannot be correct because the question states that a Class B network is used, so the number of network bits must always be 16. The two correct answers have 16 network bits (required because the question states the use of a Class B network), and at least 7 subnet and host bits each.
4. A and C. The private IPv4 networks, defined by RFC 1918, are Class A network 10.0.0.0, the 16 Class B networks from 172.16.0.0 to 172.31.0.0, and the 256 Class C networks that begin with 192.168.
5. A, D, and E. The private IPv4 networks, defined by RFC 1918, are Class A network 10.0.0.0, the 16 Class B networks from 172.16.0.0 to 172.31.0.0, and the 256 Class C networks that begin with 192.168. The three correct answers are from the public IP network range, and none are reserved values.
6. A and C. An unsubnetted Class A, B, or C network has two parts: the network and host parts.
7. B. An unsubnetted Class A, B, or C network has two parts: the network and host parts. To perform subnetting, the engineer creates a new subnet part by borrowing host bits, shrinking the number of host bits. The subnet part of the address structure exists only after the engineer chooses a nondefault mask. The network part remains a constant size.
8. C and D. Subnet ID (short for subnet identifier), subnet address, and subnet number are all synonyms and refer to the number that identifies the subnet. The actual value is a dotted-decimal number, so the term *subnet name* does not apply. The term *subnet broadcast*, a synonym for the subnet broadcast address, refers to the last (highest) numeric value in a subnet.

Chapter 12

1. B and C. Class A networks have a first octet in the range of 1–126, inclusive, and their network IDs have a 0 in the last three octets. 130.0.0.0 is actually a Class B network (first octet range 128–191, inclusive). All addresses that begin with 127 are reserved, so 127.0.0.0 is not a Class A network.
2. E. Class B networks all begin with values between 128 and 191, inclusive, in their first octets. The network ID has any value in the 128–191 range in the first octet, and any value from 0–255 inclusive in the second octet, with decimal 0s in the final two octets. Two of the answers show a 255 in the second octet, which is acceptable. Two of the answers show a 0 in the second octet, which is also acceptable.
3. B and D. The first octet (172) is in the range of values for Class B addresses (128–191). As a result, the network ID can be formed by copying the first two octets (172.16) and writing 0s for the last two octets (172.16.0.0). The default mask for all Class B networks is 255.255.0.0, and the number of host bits in all unsubnetted Class B networks is 16.
4. A and C. The first octet (192) is in the range of values for Class C addresses (192–223). As a result, the network ID can be formed by copying the first three octets (192.168.6) and writing 0 for the last octet (192.168.6.0). The default mask for all Class C networks is 255.255.255.0, and the number of host bits in all unsubnetted Class C networks is 8.
5. D. To find the network broadcast address, first determine the class, and then determine the number of host octets. At that point, convert the host octets to 255 to create the network broadcast address. In this case, 10.1.255.255 is in a Class A network, with the last three octets as host octets, for a network broadcast address of 10.255.255.255. For 192.168.255.1, it is a Class C address, with the last octet as the host part, for a network broadcast address of 192.168.255.255. Address 224.1.1.255 is a class D address, so it is not in any unicast IP network, so the question does not apply. For 172.30.255.255, it is a Class B address, with the last two octets as host octets, so the network broadcast address is 172.30.255.255.
6. B. To find the network ID, first determine the class, and then determine the number of host octets. At that point, convert the host octets to 0 to create the network ID. In this case, 10.1.0.0 is in a Class A network, with the last three octets as host octets, for a network ID of 10.0.0.0. For 192.168.1.0, it is a Class C address, with the last octet as the host part, for a network ID of 192.168.1.0. Address 127.0.0.0 looks like a Class A network ID, but it begins with a reserved value (127), so it is not in any Class A, B, or C network. 172.20.0.1 is a Class B address, with the last two octets as host octets, so the network ID is 172.20.0.0.

Chapter 13

1. C. Thinking about the conversion one octet at a time, the first two octets each convert to 8 binary 1s. 254 converts to 8-bit binary 11111110, and decimal 0 converts to 8-bit binary 00000000. So, the total number of binary 1s (which defines the prefix length) is 8+8+7+0 = /23.
2. B. Thinking about the conversion one octet at a time, the first three octets each convert to 8 binary 1s. 240 converts to 8-bit binary 11110000, so the total number of binary 1s (which defines the prefix length) is 8+8+8+4 = /28.
3. C. /24 is the equivalent of the mask that in binary has 24 binary 1s. To convert that to DDN format, write down all the binary 1s (24 in this case), followed by binary 0s for the remainder of the 32-bit mask. Then take 8 bits at a time, and convert from binary to decimal (or memorize the nine possible DDN mask octet values and their binary equivalents). Using the /24 mask in this question, the binary mask is 11111111 11111111 11111111 00000000. Each of the first three octets is all binary 1, so each converts to 255. The last octet, all binary 0s, converts to decimal 0, for a DDN mask

of 255.255.255.0. See Appendix A for a decimal/binary conversion table.

4. B. *30 is the equivalent of the mask that in binary has 30 binary 1s. To convert that to DDN format, write down all the binary 1s (30 in this case), followed by binary 0s for the remainder of the 32-bit mask. Then take 8 bits at a time, and convert from binary to decimal (or memorize the nine possible DDN mask octet values and their binary equivalents). Using the* 30 mask in this question, the binary mask is 11111111 11111111 11111111 11111100. Each of the first three octets is all binary 1, so each converts to 255. The last octet, 11111100, converts to 252, for a DDN mask of 255.255.255.252. See Appendix A for a decimal/binary conversion table.
5. C. The size of the network part is always either 8, 16, or 24 bits, based on whether it is Class A, B, or C, respectively. As a Class A address, N=8. The mask 255.255.255.0, converted to prefix format, is /24. The number of subnet bits is the difference between the prefix length (24) and N, so S=16 in this case. The size of the host part is a number that, when added to the prefix length (24), gives you 32, so H=8 in this case.
6. A. The size of the network part is always either 8, 16, or 24 bits, based on whether it is Class A, B, or C, respectively. As a Class C address, N=24. The number of subnet bits is the difference between the prefix length (27) and N, so S=3 in this case. The size of the host part is a number that, when added to the prefix length (27), gives you 32, so H=5 in this case.
7. B and D. Classless addressing rules define a two-part IP address structure: the prefix and the host part. The host part is defined the same way as with classful IP addressing rules. The classless address rules' prefix length is the length of the combined network and subnet parts when using classful IP addressing concepts. Mathematically, the prefix length is equal to the number of binary 1s in the mask. In this case, with a mask of 255.255.255.0, the prefix length is 24 bits. The host length is the number of bits added to 24 to total 32, for 8 host bits.
8. D. Classless addressing rules define a two-part IP address structure: the prefix and the host part. This logic ignores Class A, B, and C rules, and can be applied to the 32-bit IPv4 addresses from any address class. By ignoring Class A, B, and C rules, classless addressing ignores any distinction as to the network part of an IPv4 address.
9. A and B. The masks in binary define a number of binary 1s, and the number of binary 1s defines the length of the prefix (network + subnet) part. With a Class B network, the network part is 16 bits. To support 100 subnets, the subnet part must be at least 7 bits long. Six subnet bits would supply only 2^6 = 64 subnets, while 7 subnet bits supply 2^7 = 128 subnets. The /24 answer supplies 8 subnet bits, and the 255.255.255.252 answer supplies 14 subnet bits.

Chapter 14

1. D. When using classful IP addressing concepts as described in Chapter 13, "Analyzing Subnet Masks," addresses have three parts: network, subnet, and host. For addresses in a single classful network, the network parts must be identical for the numbers to be in the same network. For addresses in the same subnet, both the network and subnet parts must have identical values. The host part differs when comparing different addresses in the same subnet.
2. B and D. In any subnet, the subnet ID is the smallest number in the range, the subnet broadcast address is the largest number, and the usable IP addresses sit between them. All numbers in a subnet have identical binary values in the prefix part (classless view) and network + subnet part (classful view). To be the lowest number, the subnet ID must have the lowest possible binary value (all 0s) in the host part. To be the largest number, the broadcast address must have the highest possible binary value (all binary 1s) in the host part. The usable addresses do not include the subnet ID and subnet broadcast address, so the addresses in the range of usable IP address never have a value of all 0s or 1s in their host parts.
3. C. The mask converts to 255.255.255.0. To find the subnet ID, for each octet of the mask that is 255, you can copy the IP address's corresponding values. For mask octets of decimal 0, you can record a 0 in that octet of the subnet ID. As such, copy the 10.7.99 and write a 0 for the fourth octet, for a subnet ID of 10.7.99.0.
4. C. First, the resident subnet (the subnet ID of the subnet in which the address resides) must be numerically smaller than the IP address, which rules out one of the answers. The mask converts to 255.255.255.252. As such, you can copy the first three octets of the IP address because of their value of 255. For the fourth octet, the subnet ID value must be a multiple of 4, because 256 – 252 (mask) = 4. Those multiples include 96 and 100, and the right choice is the multiple closest to the IP address value in that octet (97) without going over. So, the correct subnet ID is 192.168.44.96.
5. C. The resident subnet ID in this case is 172.31.77.192. You can find the subnet broadcast address based on the subnet ID and mask using several methods. Following the decimal process in the book, the mask converts to 255.255.255.224, making the interesting octet be octet 4, with magic number 256 – 224 = 32. For the three octets where the mask = 255, copy the subnet ID (172.31.77). For the interesting octet, take the subnet ID value (192), add magic (32), and subtract 1, for 223. That makes the subnet broadcast address 172.31.77.223.
6. C. To answer this question, you need to find the range of addresses in the subnet, which typically then means you need to calculate the subnet ID and subnet broadcast address. With subnet ID/mask of 10.1.4.0/23, the mask converts to 255.255.254.0. To find the subnet broadcast address, following the decimal process described in this chapter, you can copy the subnet ID's first two octets because the mask's value is 255 in each octet. You write a 255 in the fourth octet because the mask has a 0 on the fourth octet. In octet 3, the interesting octet, add the magic number (2) to the subnet ID's value (4), minus 1, for a value of 2 + 4 – 1 = 5. (The magic number in this case is calculated as 256 – 254 = 2.) That makes the broadcast address 10.1.5.255. The last usable address is 1 less: 10.1.5.254. The range that includes the last 100 addresses is 10.1.5.155–10.1.5.254.
7. B. To answer this question, you do not actually need to calculate the subnet broadcast address, because you only need to know the low end of the range of addresses in the subnet. The first IP address in the subnet is 1 more than the subnet ID, or 192.168.9.97. The first 20 addresses then include 192.168.9.97–192.168.9.116.

Chapter 15

1. B and E. Cisco routers have an on/off switch, but Cisco switches generally do not.
2. A. Both switches and routers configure IP addresses, so the **ip address** *address mask* and **ip address dhcp** commands could be used on both routers and switches. The **interface vlan 1** command applies only to switches.
3. B and D. To route packets, a router interface must have an IP address assigned and be in an "up and up" interface state. For a serial link created in a lab, without using CSU/DSUs, one router must be configured with a **clock rate** command to the speed of the link. The **bandwidth** and **description** commands are not required to make a link operational.
4. C. If the first of the two status codes is "down," it typically means that a Layer 1 problem exists (for example, the physical cable is not connected to the interface).
5. C and E. The **show ip interface brief** command lists all the interface IPv4 addresses but none of the masks. The **show version** command lists none of the IP addresses and none of the masks. The other three commands list both the address and mask.
6. B. A router has one IPv4 address for each interface in use, whereas a LAN switch has a single IPv4 address that is just used for accessing the switch. The rest of the answers list configuration settings that use the same conventions on both routers and switches.

Chapter 16

1. B. PCs use two-option logic: send local packets (destined for hosts in the same subnet) directly, and send remote packets (destined for hosts in other subnets) to the default gateway/router. In this case, the PC's own IP address is 192.168.5.77, with mask 255.255.224.0, so it is in subnet 192.168.4.64/27. This subnet has a range of addresses from 192.168.4.64 to 192.168.4.95, including the subnet and broadcast address. As a result, the PC sends the packet to its default gateway. As for the other incorrect answers, if the **ping** command had used a host name, it would have first asked a DNS server to resolve the name. Also, the PC already has an IP address, so DHCP would not be needed.
2. A and C. The route defines the group of addresses represented by the route using the subnet ID and mask. The router can use those numbers to find the range of addresses that should be matched by this route. The other two answers list facts useful when forwarding packets that happen to match the route.
3. A and F. Of all the commands listed, only the two correct answers are syntactically correct router configuration commands. The command to enable 802.1Q trunking is **encapsulation dot1q** *vlan_id*.
4. C. With the **no ip subnet-zero** command configured, the router will not allow any interfaces to be configured with an IP address in the zero subnet. Of the listed answers, subnet 10.0.0.0 255.254.0.0 is a zero subnet, with a range of addresses from 10.0.0.1 to 10.1.255.254. The **ip address 10.1.2.2 255.254.0.0** command would be rejected.
5. C. The configuration of the Layer 3 switch's routing feature uses VLAN interfaces, with the interface number matching the VLAN ID. The matching connected routes, like all connected IP routes, will list the interfaces but not a next-hop IP address. The three connected routes will list the VLAN interfaces 1, 2, and 3, respectively.
6. C. The **ip route** command can refer to the IP address of the next-hop router or to the local router's interface. It also refers to the subnet ID and matching subnet mask, defining the range of addresses matched by the route.
7. A. The correct syntax lists a subnet number, then a subnet mask in dotted-decimal form, and then either an outgoing interface or a next-hop IP address.

Chapter 17

1. D and E. Both versions of RIP use distance vector logic, and EIGRP uses a different kind of logic, characterized either as advanced distance vector or a balanced hybrid.
2. C and D. Both versions of RIP use the same hop-count metric.
3. B, C, D, and E. Only the old RIP Version 1 (RIP-1) protocol does not support variable-length subnet masks (VLSM).
4. B. Link-state protocols do not exchange data that lists routes. They do list metric information, but it is per-interface information, and it is not tied to a subnet. Link-state protocols do require the SPF algorithm to take the varied pieces of information and create routes based on that information.
5. A and D. OSPF uses the SPF algorithm, conceived by a mathematician named Dijkstra.
6. B. The **network 10.0.0.0 0.255.255.255 area 0** command works, because it matches all interfaces whose first octet is 10. The rest of the commands match as follows: all addresses that end with 0.0.0 (wildcard mask 255.0.0.0); all addresses that begin with 10.0.0 (wildcard mask 0.0.0.255); and all addresses that begin 10.0 (wildcard mask 0.0.255.255).
7. A. The **network 0.0.0.0 255.255.255.255 area 0** command matches all IP addresses as a result of the 255.255.255.255 wildcard mask, so this command enables OSPF in Area 0 on all interfaces. The answer with wildcard mask 0.255.255.0 is illegal, because it represents more than one string of binary 0s separated by binary 1s. The answer with x's is syntactically incorrect. The answer with wildcard mask 255.0.0.0 means "Match all addresses whose last three octets are 0.0.0," so none of the three interfaces are matched.
8. A and E. Of the three wrong answers, two are real commands that simply do not happen to list the OSPF neighbors. **show ip ospf interface brief** lists interfaces on which OSPF is enabled, but does not list neighbors. **show ip interface** lists IPv4 details about interfaces, but none related to OSPF. One incorrect answer, **show ip neighbor**, is not a valid IOS command.

Chapter 18

1. B and D. The client sends a Discover message, with the server returning an Offer message. The client then sends a

Request, with the server sending back the IP address in the Acknowledgment message.

2. E. Of the commands in the answers, three list syntactically correct commands, but one does not: **ip dhcp-server 10.1.10.1**. The answer with this command is incorrect. The **ip helper-address 10.1.10.1** command is indeed needed as an interface subcommand, but only on remote routers like the Boston router. This command is not needed for the DNS server, so while the **ip helper-address 10.1.10.2** command would be accepted, it does not help DNS or DHCP work. Finally, the **ip name-server 10.1.10.2** command on the Atlanta router works, but it simply lets users of the Atlanta router CLI make use of the DNS server; it has no effect on user DNS traffic.
3. B. The configuration puts the per-client settings in a DHCP pool: client IP address, mask, default router, and DNS server IP addresses. The pool also lists the length of time for which the client can keep the lease for the address. Only the exclude list (**ip dhcp exclude-address**) sits outside the DHCP pool.
4. B and D. A PC needs to know its own IP address, the associated mask, the IP address of the default router, and the IP addresses of the DNS servers.
5. A. A ping of a host's own IP address does not test whether the LAN is working, because the packet does not have to traverse the LAN. A ping that requires the packet to go from PC1 to the default gateway (R1) proves the LAN works, at least between PC1 and R1. The only answer that lists a command that causes a packet to need to cross the LAN from PC1 to R1 (although that process fails) is the **ping 10.1.1.1** command.
6. A, C, and E. The **tracert** (Microsoft operating systems) and **traceroute** (Cisco IOS Software) commands list the IP address of the intermediate routers and end host. The commands list the router's IP address closest to the host that issued the command.
7. C. The asterisk beside connection 2 identifies the connection number to which the **resume** command will connect the user if the **resume** command does not have any parameters.

Chapter 19

1. A. With 50 percent growth, the mask needs to define enough subnet bits to create 150 subnets. As a result, the mask needs at least 8 subnet bits (7 subnet bits supply 2^7, or 128, subnets, and 8 subnet bits supply 2^8, or 256, subnets). Similarly, the need for 50 percent growth in the size for the largest subnet means that the host part needs enough bits to number 750 hosts/subnet. Nine host bits are not enough ($2^9 - 2 = 510$), but 10 host bits supply 1022 hosts/subnet ($2^{10} - 2 = 1022$). With 16 network bits existing because of the choice to use a Class B network, the design needs a total of 34 bits (at least) in the mask (16 network, 8 subnet, 10 host), but only 32 bits exist—so no single mask meets the requirements.
2. B. With a growth of 20 percent, the design needs to support 240 subnets. To meet that need, 7 subnet bits do not meet the need ($2^7 = 128$), but 8 subnet bits do meet the need ($2^8 = 256$). Similarly, the minimum number of host bits is also 8, because the need, after the 20 percent growth, would be 144 hosts/subnet. That number requires 8 host bits ($2^8 - 2 = 254$). These numbers are minimum numbers of subnet and host bits.

   The right answer, 10.0.0.0/22, has 8 network bits because the network class is Class A, 14 subnet bits (/22 – 8 = 14), and 10 host bits (32 – 22 = 10). This mask supplies at least 8 subnet bits and at least 8 host bits. The masks in the other answers either do not supply at least 8 host bits or do not supply at least 8 subnet bits.
3. B. To support 1000 subnets, 10 subnet bits ($2^{10} = 1024$) are needed. The design uses a Class B network, which means that 16 network bits exist as well. So, the shortest mask that meets the requirements is 255.255.255.192, or *26, comprised of 16 network plus 10 subnet bits. The* 28 answer also supplies enough subnets to meet the need, but compared to *26,* 28 supplies fewer host bits and so fewer hosts/subnet.
4. D. To choose the mask that maximizes the number of subnets, choose the mask that uses the minimum number of host bits, which in turn maximizes the number of subnet bits. In this case, the design requires 200 hosts/subnet. Seven host bits do not supply enough hosts per subnet ($2^7 - 2 = 126$), but 8 host bits do supply enough hosts per subnet ($2^8 - 2 = 254$). The design uses a Class A network, with 8 network bits. A prefix mask of *24 (a mask with 8 host bits, the minimum to support the right number of hostssubnet)* maximizes the size of the subnet part, in this case supplying 16 subnet bits.
5. C and D. The mask converts to 255.255.252.0, so the difference from subnet ID to subnet ID (called the magic number in this chapter) is 256 – 252 = 4. So, the subnet IDs start with 172.30.0.0, then 172.30.4.0, then 172.30.8.0, and so on, adding 4 to the third octet. The mask, used with a Class B network, implies 6 subnet bits, for 64 total subnet IDs. The last of these, 172.30.252.0, can be recognized in part because the third octet, where the subnet bits sit, has the same value as the mask in that third octet.
6. A. The first (numerically lowest) subnet ID is the same number as the classful network number, or 192.168.9.0. The remaining subnet IDs are each 8 larger than the previous subnet ID, in sequence, or 192.168.9.8, 192.168.9.16, 192.168.9.24, 192.168.9.32, and so on, through 192.168.9.248.
7. D. Using mask *24 (255.255.255.0), the subnet IDs increment by 1 in the third octet. The reasoning is that with a Class B network, 16 network bits exist, and with mask* 24, the next 8 bits are subnet bits, so the entire third octet contains subnet bits. All the subnet IDs will have a 0 as the last octet, because the entire fourth octet consists of host bits. Note that 172.19.0.0 (the zero subnet) and 172.19.255.0 (the broadcast subnet) might look odd, but are valid subnet IDs.
8. D. Following the processes in this chapter, this Class A network and /25 mask defines 8 network bits (per the class) and 17 subnet bits (all of octets 2 and 3, plus 1 subnet bit in octet 4). As such, the magic number can be used in the fourth octet to find the value to add to the previous subnet ID to find the next subnet ID. The magic number in this case is 256 – 128 = 128.

   As a result, the fourth octet will be either a 0 or a 128. Octets 2 and 3 could be any value from 0 through 255 inclusive. Only one answer (10.1.1.192) breaks these range values.

Chapter 20

1. B, C, and D. Classless routing protocols, by definition, support VLSM because classless routing protocols transmit the subnet mask in their routing updates. Of the listed answers, only RIP version 1 (RIP-1) is not a classless routing protocol.
2. A. Note that sometimes VLSM stands for variable-length subnet masking, which refers to the process of using different masks in the same classful network, whereas variable-length subnet mask refers to the subnet masks themselves.
3. A. Subnet 10.5.0.0 255.255.240.0 implies range 10.5.0.0–10.5.15.255, which does not overlap. 10.4.0.0 255.254.0.0 implies range 10.4.0.0–10.5.255.255, which does overlap. 10.5.32.0 255.255.224.0 implies range 10.5.32.0–10.5.63.255, which does overlap. 10.5.0.0 255.255.128.0 implies range 10.5.0.0–10.5.127.255, which does overlap.
4. D. The four answers imply the following ranges: 172.16.0.0/21: 172.16.0.0–172.16.7.255. 172.16.6.0/23: 172.16.6.0–172.16.7.255. 172.16.16.0/20: 172.16.16.0–172.16.31.255. 172.16.11.0/25: 172.16.11.0–172.16.11.255. The subnet in the question, 172.16.8.0/22, implies a range of 172.16.8.0–172.16.11.127, which includes the range of numbers in subnet 172.16.11.0/25.
5. C. The question lists three existing subnets, which together consume part of Class C network 192.168.1.0. Just listing the last octet values, these subnets consume 0–63, 128–131, and 160–167. The new subnet, with a *28 mask, needs 16 consecutive numbers, and the subnet numbers will all be a multiple of 16 in the last octet (0, 16, 32, and so on). Looking at the consumed numbers again, the first opening starts at 64 and runs up through 127, so it has more than enough space for 16 addresses. So the numerically lowest subnet number is 192.168.1.64*28, with range 192.168.1.64–192.168.1.79.

Chapter 21

1. C. All the listed answers include the range of all three subnets, except for 10.3.64.0 255.255.224.0, which implies an address range of 10.3.64.0–10.3.95.255. Of the other three answers, 10.3.64.0 255.255.192.0 is the smallest range (10.3.64.0–10.3.127.255). It also happens to be the smallest single summary route that includes all three subnets listed in the question.
2. C and D. 10.0.0.0 255.0.0.0 implies a range of all addresses that begin with 10, and 10.1.0.0 255.255.0.0 implies a range of all addresses that begin with 10.1, so both of these answers include all the address ranges listed in the question. 10.1.32.0 255.255.224.0 implies a range of 10.1.32.0–10.1.63.255, which includes all addresses listed in the question. 10.1.55.0 255.255.255.0 implies a range of only 10.1.55.0–10.1.55.255, which does not include all addresses. 10.1.48.0 255.255.248.0 implies a range of 10.1.48.0–10.1.55.255, which omits two of the subnets listed in the question.
3. D. Following the process in the book, the range of addresses in the subnets are 10.1.12.0–10.1.12.255, 10.1.14.0–10.1.14.255, and 10.1.15.0–10.1.15.255. So, the entire range includes 10.1.12.0–10.1.15.255. Then, the lowest subnet ID from the list is 10.1.12.0, and the initial value of *P to try should be* 23.

   Calculating a subnet ID and broadcast from these two numbers gives us 10.1.12.0/23, broadcast 10.1.13.255. This range does not include all addresses in the original subnets, so repeat the process with 10.1.12.0 and *22. This combination gives us subnet 10.1.12.0, broadcast 10.1.15.255, which does include all addresses, identifying the best summary as using subnet*mask 10.1.12.0/22.
4. B. Following the process in the book, the range of addresses in the subnets are 192.168.1.64–192.168.1.79, 192.168.1.80–192.168.1.95, and 192.168.1.96–192.168.1.111. So, the entire range includes 192.168.1.64–192.168.1.111. Then, the lowest subnet ID from the list is 192.168.1.64, and the initial value of *P to try should be* 27.

   Calculating a subnet ID and broadcast from these two numbers gives us 192.168.1.64/27, broadcast 192.168.1.95. This range does not include all addresses in the original subnets, so repeat the process with 192.168.1.64 and *26. This combination gives us subnet 192.168.1.64, broadcast 192.168.1.127, which does include all addresses, identifying the best summary as using subnet*mask 192.168.1.64/26.

Chapter 22

1. A and C. Standard ACLs check the source IP address. The address range 10.1.1.1–10.1.1.4 can be matched by an ACL, but it requires multiple **access-list** commands. Matching all hosts in Barney’s subnet can be accomplished with the **access-list 1 permit 10.1.1.0 0.0.0.255** command.
2. A and D. The range of valid ACL numbers for standard numbered IP ACLs is 1–99 and 1300–1999, inclusive.
3. D. 0.0.0.255 matches all packets that have the same first three octets. This is useful when you want to match a subnet in which the subnet part comprises the first three octets, as in this case.
4. E. 0.0.15.255 matches all packets with the same first 20 bits. This is useful when you want to match a subnet in which the subnet part comprises the first 20 bits, as in this case.
5. A. The router always searches the ACL statements in order, and stops trying to match ACL statements after a statement is matched. In other words, it uses first-match logic. A packet with source IP address 1.1.1.1 would match any of the three explicitly configured commands described in the question. As a result, the first statement will be used.
6. B. One wrong answer, with wildcard mask 0.0.255.0, matches all packets that begin with 172.16, with a 5 in the last octet. One wrong answer matches only specific IP address 172.16.5.0. One wrong answer uses a wildcard mask of 0.0.0.128, which has only one wildcard bit (in binary), and happens to only match addresses 172.16.5.0 and 172.16.5.128. The correct answer matches the range of addresses 172.16.4.0–172.16.5.255, which includes all addresses in the subnet listed in the question (172.16.5.0–172.16.5.127).

Chapter 23

1. E and F. Extended ACLs can look at the Layer 3 (IP) and Layer 4 (TCP, UDP) headers and a few others, but not any

application layer information. Named extended ACLs can look for the same fields as numbered extended ACLs.

2. A and E. The correct range of ACL numbers for extended IP access lists is 100 to 199 and 2000 to 2699. The answers that list the **eq www** parameter after 10.1.1.1 match the source port number, and the packets are going toward the web server, not away from it.
3. E. Because the packet is going toward any web client, you need to check for the web server's port number as a source port. The client IP address range is not specified in the question, but the servers are, so the source address beginning with 172.16.5 is the correct answer.
4. E. Named extended IP ACLs can match the exact same set of fields as can numbered extended IP ACLs.
5. A and C. Before IOS 12.3, numbered ACLs must be removed and then reconfigured to remove a line from the ACL. As of IOS 12.3, you can also use ACL configuration mode and sequence numbers to delete one ACL line at a time.
6. C. The authorized Cisco curriculum makes the suggestion in answer C for extended IP ACLs, suggesting that standard ACLs be placed as close to the destination as possible.
7. A. NTP uses protocol messages between clients and servers so that the clients can adjust their time-of-day clock to match the server. NTP is totally unrelated to serial line clocking. It also does not count CPU cycles, instead relying on messages from the NTP server. Also, the client defines the IP address of the server, and does not have to be in the same subnet.

Chapter 24

1. F. The word *classless* in this term refers to the fact that the routes advertise a block of addresses with a mask, and can essentially ignore the Class A, B, and C boundaries with regard to what address block is used. Also, because the motivation was to describe routes between different companies (different routing domains), the term uses the word *interdomain*.
2. D. CIDR's original intent was to allow the summarization of multiple Class A, B, and C networks to reduce the size of Internet routing tables. Of the answers, only 200.1.0.0 255.255.0.0 summarizes multiple networks.
3. B and E. RFC 1918 identifies private network numbers. It includes Class A network 10.0.0.0, Class B networks 172.16.0.0 through 172.31.0.0, and Class C networks 192.168.0.0 through 192.168.255.0.
4. C. With static NAT, the entries are statically configured. Because the question mentions translation for inside addresses, the **inside** keyword is needed in the command.
5. A. With dynamic NAT, the entries are created as a result of the first packet flow from the inside network.
6. A. The **list 1** parameter references an IP ACL, which matches packets, identifying the inside local addresses.
7. A and C. The configuration is missing the **overload** keyword in the **ip nat inside source** command and in the **ip nat outside** interface subcommand on the serial interface.
8. B. The last line mentions that the pool has seven addresses, with all seven allocated, with the misses counter close to 1000—meaning that close to 1000 new flows were rejected because of insufficient space in the NAT pool.

Chapter 25

1. C. NAT, specifically the PAT feature that allows many hosts to use private IPv4 addresses while being supported by a single public IPv4 address, was one short-term solution to the IPv4 address exhaustion problem. IP version 5 existed briefly as an experimental protocol and had nothing to do with IPv4 address exhaustion. IPv6 directly addresses the IPv4 address exhaustion problem, but it is a long-term solution. ARP has no impact on the number of IPv4 addresses used.
2. A. Routers use the same process steps when routing IPv6 packets as they do when routing IPv4 packets. Routers route IPv6 packets based on the IPv6 addresses, listed inside the IPv6 header in the IPv6 packets, by comparing the destination IPv6 address to the router's IPv6 routing table. As a result, the router discards the incoming frame's data link header and trailer, leaving an IPv6 packet. The router compares the destination (not source) IPv6 address in the header to the router's IPv6 (not IPv4) routing table and then forwards the packet based on the matched route.
3. D. If following the steps in the book, the first step removes up to three leading 0s in each quartet, leaving FE80:0:0:100:0:0:0:123. This leaves two strings of consecutive all-0 quartets; by changing the longest string of all 0s to ::, the address is FE80:0:0:100::123.
4. B. This question has many quartets that make it easy to make a common mistake: removing trailing 0s in a quartet of hex digits. To abbreviate IPv6 addresses, only leading 0s in a quartet should be removed. Many of the quartets have trailing 0s (0s on the right side of the quartet), so make sure to not remove those 0s.
5. A. The unabbreviated version of an IPv6 address must have 32 digits, and only one answer has 32 hex digits. In this case, the original number shows four quartets and a ::. So, the :: was replaced with four quartets of 0000, making the number have eight quartets. Then, for each quartet with fewer than four digits, leading 0s were added so that each quartet has four hex digits.
6. C. The *64 prefix length means that the last 64 bits, or last 16 digits, of the address should be changed to all 0s. That process leaves the unabbreviated prefix as 2000:0000:0000:0005:0000:0000:0000:0000. The last four quartets are all 0s, making that string of all 0s be the longest and best string of 0s to replace with ::. After removing the leading 0s in other quartets, the answer is 2000:0:0:5::*64.

Chapter 26

1. C. Unique local addresses begin with FD in the first two digits.
2. A. Global unicast addresses can begin with many different initial values, but most commonly, they begin with either a

hex 2 or 3.

3. D. The global routing prefix is the address block, represented as a prefix value and prefix length, given to an organization by some numbering authority. All IPv6 addresses inside the company have the same value in these initial bits of their IPv6 addresses. Similarly, when a company uses a public IPv4 address block, all the addresses have the same value in the network part.
4. B. Subnetting a global unicast address block, using a single prefix length for all subnets, breaks the addresses into three parts. The parts are the global routing prefix, subnet, and interface ID.
5. D. Unique local addresses begin with a 2-hex-digit prefix of FD, followed by the 10-hex-digit global ID.

Chapter 27

1. A. The one correct answer lists the exact same IPv6 address listed in the question, with a /64 prefix length, and no spaces in the syntax of the answer. Another (incorrect) answer is identical, except it leaves a space between the address and prefix length, which is incorrect syntax. The two answers that list the **eui-64** parameter both list an address and not a prefix; they should list a prefix to be correct, although neither would have resulted in the IPv6 address listed in the question.
2. B. With the **eui-64** parameter, the router will calculate the interface ID portion of the IPv6 address based on its MAC address. Beginning with 5055.4444.3333, the router injects FF FE in the middle (5055.44FF.FE44.3333). Then, the router inverts the seventh bit in the first byte. Mentally, this converts hex 50 to binary 01010000, changing bit 7 so that the string is 0101 0010, and converting back to hex 52. The final interface ID value is 5255:44FF:FE44:3333. The wrong answers simply list a different value.
3. A and C. Of the four answers, the two correct answers show the minimal required configuration to support IPv6 on a Cisco router: enabling IPv6 routing (**ipv6 unicast-routing**) and enabling IPv6 on each interface, typically by adding a unicast address to each interface (**ipv6 address…**). The two incorrect answers list nonexistent commands.
4. A. With an **ipv6 address** command configured for a global unicast address, but without a link-local address configured with an **ipv6 address** command, the router calculates its link-local address on the interface based on its MAC address and EUI-64 rules. The first half of the link-local address begins FE80:0000:0000:0000. The router then calculates the second half of the link-local address value by taking the MAC address (0200.0001.000A), injecting FF FE in the middle (0200.00FF.FE01.000A), and flipping the seventh bit (0000.00FF.FE01.000A).
5. B. FF02::1 is used by all IPv6 hosts on the link, FF02::5 is used by all OSPFv3 routers, and FF02::A is used by all EIGRPv6 routers. FF02::2 is used to send packets to all IPv6 routers on a link.
6. C. R1 will form the solicited node multicast address by using a format of FF02::1:FFxx:xxxx, replacing xx:xxxx with the last six hex digits of the unicast address. If the link-local address and unicast address have different values in their last six hex digits, the router creates a solicited node multicast for both. To form the solicited node multicast address FF02::1:FF00:A, the last six hex digits of an address must be hex 00:000A. Of three answers that define an IPv6 unicast addresses, only one lists a value whose last six hex digits are 00:000A. Also, in this case, the link-local address will be FE80::FF:FE01:A, resulting in a solicited node multicast address of FF02::1:FF01:A, which is not the address listed in the question.

Chapter 28

1. B. PC1 needs to discover PC2's MAC address. Unlike IPv4, IPv6 does not use ARP, instead using NDP. Specifically, PC1 uses the NDP Neighbor Solicitation (NS) message to request that PC2 send back an NDP Neighbor Advertisement (NA). SLAAC relates to address assignment, and not to discovering a neighbor's MAC address.
2. D. Hosts can ask for (solicit) all routers to identify themselves by sending an NDP Router Solicitation (RS) message, with the routers sending back an NDP Router Advertisement (RA) message. NDP Neighbor Solicitation (NS) can also be used by PC1, but not for the purpose of learning its default router IPv6 address. DAD is a function that happens to use NDP NS and NA messages, but its function does not include the discovery of the default router address. Finally, EUI-64 does not define a protocol or message.
3. A and C. The NDP RA lists the router IPv6 address, the IPv6 prefixes known on the link, and the matching prefix lengths. When using DHCPv6, the host learns the IPv6 address of the DNS server through DHCPv6 messages. For MAC addresses of on-link neighbors, hosts use NDP NS and NA messages.
4. C. Hosts use NDP messages, namely Router Solicitation (RS) and Router Advertisement (RA), to learn the IPv6 address of potential default routers. The other settings typically come from the stateful DHCPv6 server.
5. D. SLAAC gives the host a means to choose its unicast address. The host also uses NDP to learn its prefix length, plus the address(es) of any default routers. It then uses stateless DHCP to learn the addresses of the DNS server(s).
6. B and D. With SLAAC, the host learns the prefix from a router using NDP RS/RA messages, and then the host builds the rest of the address (the interface ID). The host can use EUI-64 rules or use a defined process to randomly generate the interface ID value. The host does not learn the interface ID from any other device, which helps make the process stateless, because no other device needs to assign the host its full address.
7. A. The **show ipv6 neighbors** command lists all IPv6 addresses of neighbors (both routers and hosts), plus their matching MAC addresses. It does not note which are routers, leaving that information for the **show ipv6 routers** command.

Chapter 29

1. A and C. With an IPv6 address on a working interface, the router adds a connected route for the prefix (subnet) implied by the **ipv6 address** command. It also adds a local host route (with a /128 prefix length) based on the unicast address. The router does not add a route based on the link-local address.

2. A. All four answers show examples of commands that use an outgoing interface. The two commands that begin with **ip route** define only IPv4 routes; the commands would be rejected because of the IPv6 prefixes listed in the commands. The two commands that begin with **ipv6 route** are syntactically correct, but the command should list the local router's interface (an interface on the router on which the command is being configured). R5 needs to use its local S0/1/1 interface as the outgoing interface.
3. B. All four answers show examples of commands that use a next-hop router IPv6 address. Two of the answers list R5's own IPv6 address (unicast or link-local), which is incorrect; the address should be an address on the neighboring router, R6 in this case. For the two answers that list addresses on Router R6, the one that lists R6's global unicast address is correct. The one that lists R6's link-local address would also require R5's outgoing interface, so the answer that lists FE80::FF:FE00:6 would be rejected as well.
4. A and D. Because the router already has IPv4 configured, the new IPv6 OSPFv3 process will be able to choose its own router ID automatically. So, the **router-id** command for OSPFv3 (one of the answers), while valid, is not required. OSPFv3 does not use a **network** *prefix/length* command, so that answer is not correct. The other two answers list commands required for the configuration.
5. B and D. The **show ipv6 ospf interface brief** command lists one line of output for each interface on which OSPV3 is enabled. The **show ipv6 protocols** command lists information about all sources of IPv6 routing information; the messages about OSPFv3 list the interfaces on which it is enabled.
6. B and C. OSPFv2 support IPv4 routes, while OSPFv3 supports IPv6. EIGRP for IPv6 is typically called EIGRPv6.

Appendix D. Practice for Chapter 12: Analyzing Classful IPv4 Networks

Practice Problems

The practice problems in this appendix require that you determine a few basic facts about a network, given an IP address and an assumption that subnetting is not used in that network. To do so, refer to the processes described in Chapter 12 of *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*.

In particular, for the upcoming list of IP addresses, you should identify the following information:

- Class of the address
- Number of octets in the network part of the address
- Number of octets in the host part of the address
- Network number
- Network broadcast address

Find all these facts for the following IP addresses:

1. 10.55.44.3
2. 128.77.6.7
3. 192.168.76.54
4. 190.190.190.190
5. 9.1.1.1
6. 200.1.1.1
7. 201.1.77.5
8. 101.1.77.5
9. 119.67.99.240
10. 219.240.66.98

Answers

The process to answer these problems is relatively basic, so this section reviews the overall process and then lists the answers to problems 1–10.

The process starts by examining the first octet of the IP address:

- If the first octet of the IP address is a number between 1 and 126, inclusive, the address is a Class A address.
- If the first octet of the IP address is a number between 128 and 191, inclusive, the address is a Class B address.
- If the first octet of the IP address is a number between 192 and 223, inclusive, the address is a Class C address.

When no subnetting is used:

- Class A addresses have one octet in the network part of the address and three octets in the host part.
- Class B addresses have two octets each in the network and host part.
- Class C addresses have three octets in the network part and one octet in the host part.

After determining the class and the number of network octets, you can easily find the network number and network broadcast address. To find the network number, copy the network octets of the IP address and write down 0s for the host octets. To find the network broadcast address, copy the network octets of the IP address and write down 255s for the host octets.

Table D-1 lists all six problems and their respective answers.

Table D-1. Answers to Problems

IP Address	Class	Number of Network Octets	Number of Host Octets	Network Number	Network Broadcast Address
10.55.44.3	A	1	3	10.0.0.0	10.255.255.255
128.77.6.7	B	2	2	128.77.0.0	128.77.255.255
192.168.76.54	C	3	1	192.168.76.0	192.168.76.255
190.190.190.190	B	2	2	190.190.0.0	190.190.255.255
9.1.1.1	A	1	3	9.0.0.0	9.255.255.255
200.1.1.1	C	3	1	200.1.1.0	200.1.1.255
201.1.77.55	C	3	1	201.1.77.0	201.1.77.255
101.1.77.55	A	1	3	101.0.0.0	101.255.255.255
119.67.99.240	A	1	3	119.0.0.0	119.255.255.255
219.240.66.98	C	3	1	219.240.66.0	219.240.66.255

Appendix E. Practice for Chapter 13: Analyzing Subnet Masks

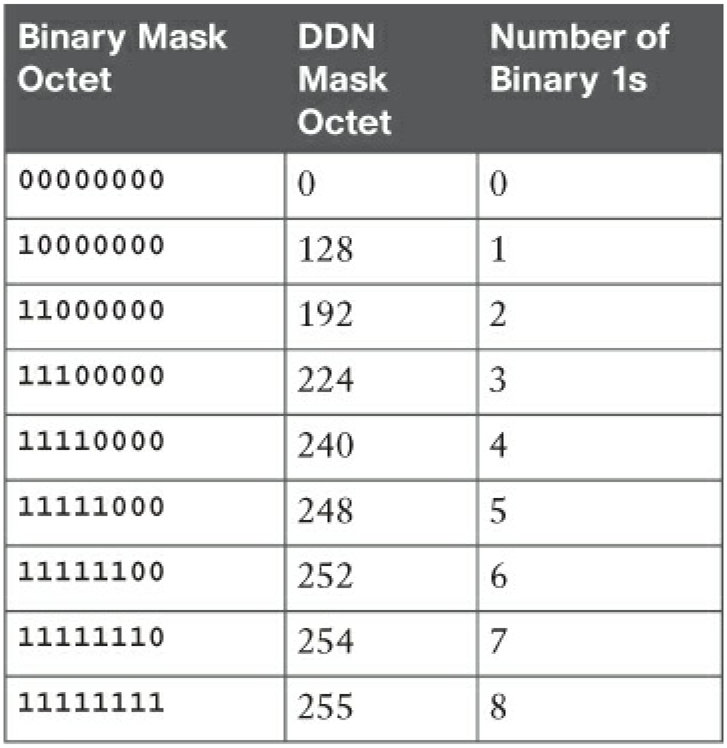
This appendix begins with ten mask conversion problems, followed by the matching answers and explanations. After that, the appendix lists ten mask analysis problems, with the matching answers to follow.

Mask Conversion Problems

The problems in this appendix require you to convert dotted-decimal subnet masks to prefix format and vice versa. To do so, feel free to use the processes described in Chapter 13 of *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*.

Many people use the information in Table E-1 when converting masks. The table lists the nine dotted-decimal notation (DDN) mask values, the binary equivalent, and the number of binary 1s in the binary equivalent.

Table E-1. Nine Possible Values in One Octet of a Subnet Mask



Binary Mask Octet	DDN Mask Octet	Number of Binary 1s
00000000	0	0
10000000	128	1
11000000	192	2
11100000	224	3
11110000	240	4
11111000	248	5
11111100	252	6
11111110	254	7
11111111	255	8

Convert each DDN mask to prefix format and vice versa:

1. 255.240.0.0
2. 255.255.192.0
3. 255.255.255.224
4. 255.254.0.0.
5. 255.255.248.0
6. /30
7. /25
8. /11
9. /22
10. /24

Answers to Mask Conversion Problems

Mask Conversion Problem 1: Answer

The answer is /12.

The binary process for converting the mask from dotted-decimal format to prefix format is relatively simple. The only hard part is converting the dotted-decimal number to binary. For reference, the process is as follows:.

Step 1. Convert the dotted-decimal mask to binary.

Step 2. Count the number of binary 1s in the 32-bit binary mask; this is the value of the prefix notation mask.

For problem 1, mask 255.240.0.0 converts to

11111111 11110000 00000000 00000000

You can see from the binary number that it contains 12 binary 1s, so the prefix format of the mask will be /12.

You can find the same answer without converting decimal to binary if you have memorized the nine DDN mask values, and the corresponding number of binary 1s in each, as listed earlier in Table E-1. Follow these steps:

Step 1. Start with a prefix value of 0.

Step 2. (1st octet) Add 8 because the first mask octet of 255 includes eight binary 1s.

Step 3. (2nd octet) Add 4 because the second mask octet of 240 includes four binary 1s.

Step 4. The resulting prefix is /12.

Mask Conversion Problem 2: Answer

The answer is /18.

For problem 2, mask 255.255.192.0 converts to the following:

11111111 11111111 11000000 00000000

You can see from the binary number that it contains 18 binary 1s, so the prefix format of the mask will be /18.

If you memorized the number of binary 1s represented by each DDN mask value, you can possibly work faster with the following logic:

Step 1. Start with a prefix value of 0.

Step 2. (1st octet) Add 8 because the first mask octet of 255 includes eight binary 1s.

Step 3. (2nd octet) Add 8 because the second mask octet of 255 includes eight binary 1s.

Step 4. (3rd octet) Add 2 because the *third* mask octet of 192 includes two binary 1s.

Step 5. The resulting prefix is /18.

Mask Conversion Problem 3: Answer

The answer is /27.

For problem 3, mask 255.255.255.224 converts to the following:

11111111 11111111 11111111 11100000

You can see from the binary number that it contains 27 binary 1s, so the prefix format of the mask will be /27.

If you memorized the number of binary 1s represented by each DDN mask value, you can possibly work faster with the following logic:

Step 1. Start with a prefix value of 0.

Step 2. (1st octet) Add 8 because the first mask octet of 255 includes eight binary 1s.

Step 3. (2nd octet) Add 8 because the second mask octet of 255 includes eight binary 1s.

Step 4. (3rd octet) Add 8 because the third mask octet of 255 includes eight binary 1s.

Step 5. (4th octet) Add 3 because the fourth mask octet of 224 includes three binary 1s.

Step 6. The resulting prefix is /27.

Mask Conversion Problem 4: Answer

The answer is /15.

For problem 4, mask 255.254.0.0 converts to the following:

11111111 11111110 00000000 00000000

You can see from the binary number that it contains 15 binary 1s, so the prefix format of the mask will be /15.

If you memorized the number of binary 1s represented by each DDN mask value, you can possibly work faster with the following logic:

Step 1. Start with a prefix value of 0.

Step 2. (1st octet) Add 8 because the first mask octet of 255 includes eight binary 1s.

Step 3. (2nd octet) Add 7 because the second mask octet of 254 includes seven binary 1s.

Step 4. The resulting prefix is /15.

Mask Conversion Problem 5: Answer

The answer is /21.

For problem 5, mask 255.255.248.0 converts to the following:

11111111 11111111 11111000 00000000

You can see from the binary number that it contains 21 binary 1s, so the prefix format of the mask will be /21.

If you memorized the number of binary 1s represented by each DDN mask value, you can possibly work faster with the following logic:

Step 1. Start with a prefix value of 0.

Step 2. (1st octet) Add 8 because the first mask octet of 255 includes eight binary 1s.

Step 3. (2nd octet) Add 8 because the second mask octet of 255 includes eight binary 1s.

Step 4. (3rd octet) Add 5 because the third mask octet of 248 includes five binary 1s.

Step 5. The resulting prefix is /21.

Mask Conversion Problem 6: Answer

The answer is 255.255.255.252.

The binary process for converting the prefix version of the mask to dotted-decimal is straightforward, but again requires some binary math. For reference, the process runs like this:

Step 1. Write down x binary 1s, where x is the value listed in the prefix version of the mask.

Step 2. Write down binary 0s after the binary 1s until the combined 1s and 0s form a 32-bit number.

Step 3. Convert this binary number, 8 bits at a time, to decimal, to create a dotted-decimal number; this value is the dotted-decimal version of the subnet mask. (Refer to Table E-1, which lists the binary and decimal equivalents.)

For problem 6, with a prefix of /30, you start at Step 1 by writing down 30 binary 1s, as shown here:

11111111 11111111 11111111 111111

At Step 2, you add binary 0s until you have 32 total bits, as shown next:

11111111 11111111 11111111 111111**00**

The only remaining work is to convert this 32-bit number to decimal, remembering that the conversion works with 8 bits at a time.

Mask Conversion Problem 7: Answer

The answer is 255.255.255.128.

For problem 7, with a prefix of /25, you start at Step 1 by writing down 25 binary 1s, as shown here:

11111111 11111111 11111111 1

At Step 2, you add binary 0s until you have 32 total bits, as shown next:

11111111 11111111 11111111 1**0000000**

The only remaining work is to convert this 32-bit number to decimal, remembering that the conversion works with 8 bits at a time.

Mask Conversion Problem 8: Answer

The answer is 255.224.0.0.

For problem 8, with a prefix of /11, you start at Step 1 by writing down 11 binary 1s, as shown here:

11111111 111

At Step 2, you add binary 0s until you have 32 total bits, as shown next:

11111111 111**00000 00000000 00000000**

The only remaining work is to convert this 32-bit number to decimal, remembering that the conversion works with 8 bits at a time.

Mask Conversion Problem 9: Answer

The answer is 255.255.252.0.

For problem 9, with a prefix of /22, you start at Step 1 by writing down 22 binary 1s, as shown here:

11111111 11111111 111111

At Step 2, you add binary 0s until you have 32 total bits, as shown next:

11111111 11111111 111111**00 00000000**

The only remaining work is to convert this 32-bit number to decimal, remembering that the conversion works with 8 bits at a time.

Mask Conversion Problem 10: Answer

The answer is 255.255.255.0.

For problem 10, with a prefix of /24, you start at Step 1 by writing down 24 binary 1s, as shown here:

11111111 11111111 11111111

At Step 2, you add binary 0s until you have 32 total bits, as shown next:

11111111 11111111 11111111 **00000000**

The only remaining work is to convert this 32-bit number to decimal, remembering that the conversion works with 8 bits at a time.

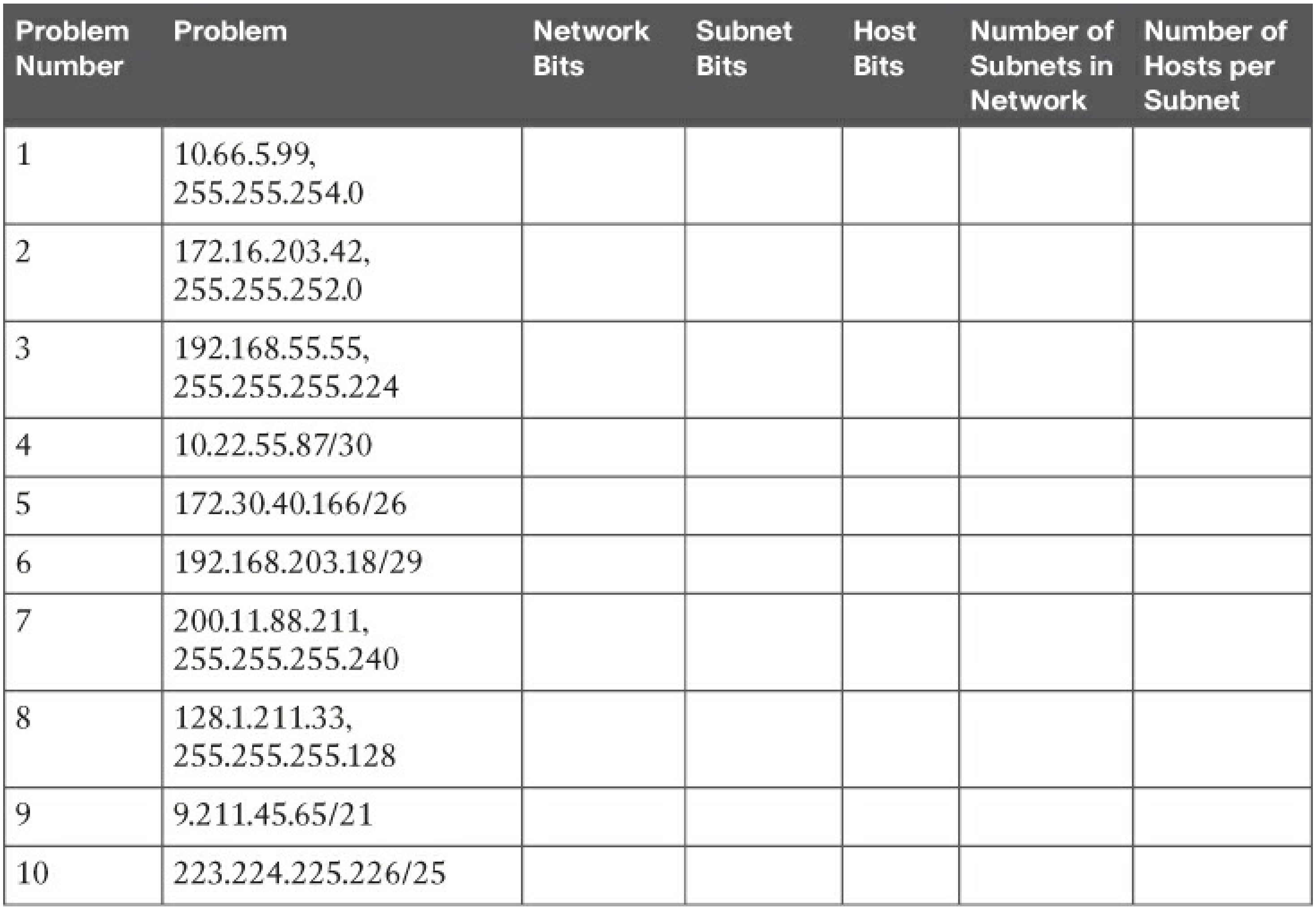
Mask Analysis Problems

This appendix lists problems that require you to analyze an existing IP address and mask to determine the number of network, subnet, and host bits. From that, you should calculate the number of subnets possible when using the listed mask in the class of network shown in the problem, as well as the number of possible host addresses in each subnet.

To find this information, you can use the processes explained in Chapter 13 of *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*. When doing the problems, Table E-1, earlier in this appendix, which lists all possible DDN mask values, can be useful.

Each row of Table E-2 lists an IP address and mask. For each row, complete the table. Note that for the purposes of this exercise, you can assume that the two special subnets in each network, the zero subnet and broadcast subnet, are allowed to be used.

Table E-2. Mask Analysis Problems

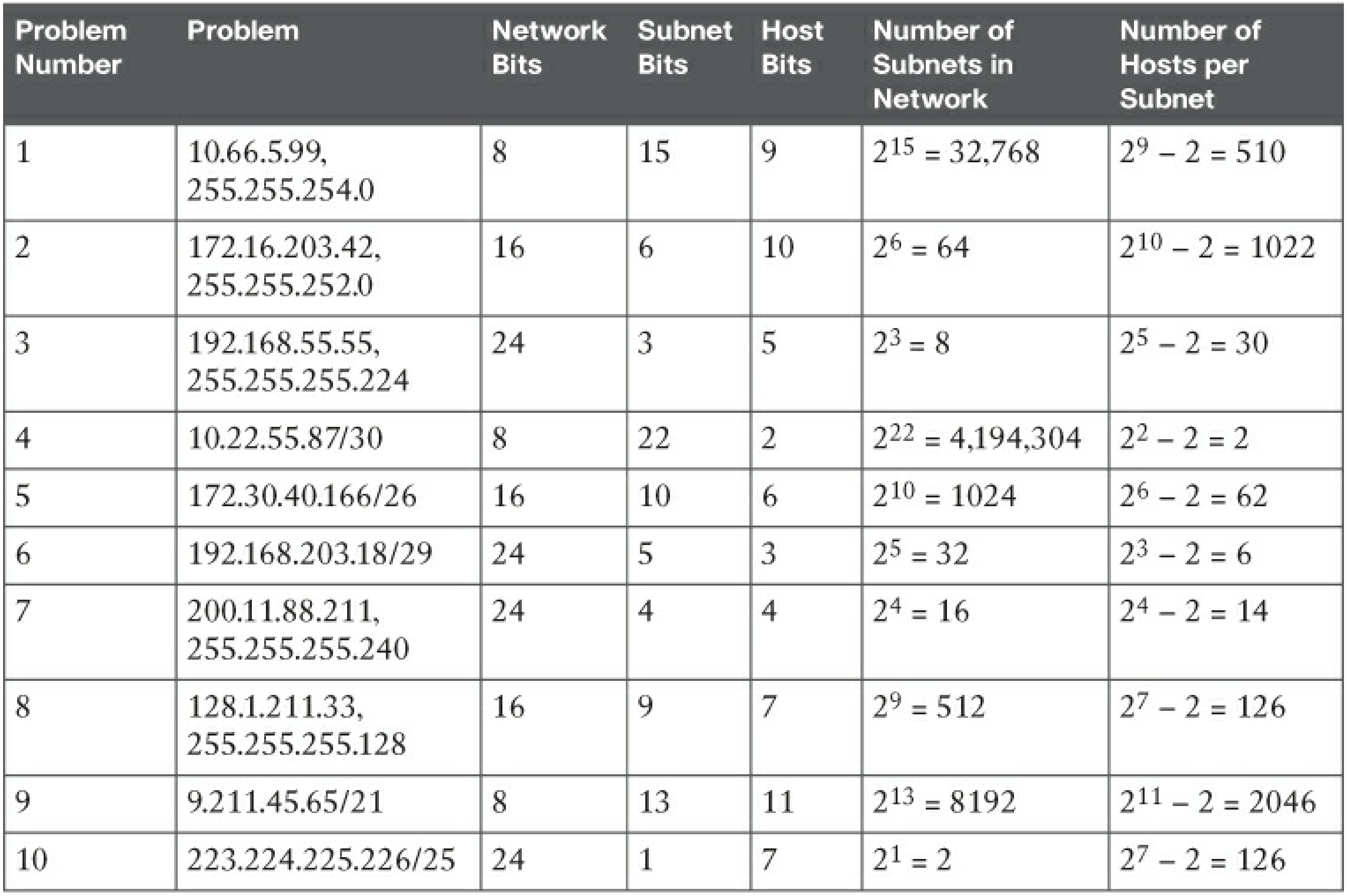


Problem Number	Problem	Network Bits	Subnet Bits	Host Bits	Number of Subnets in Network	Number of Hosts per Subnet
1	10.66.5.99, 255.255.254.0					
2	172.16.203.42, 255.255.252.0					
3	192.168.55.55, 255.255.255.224					
4	10.22.55.87/30					
5	172.30.40.166/26					
6	192.168.203.18/29					
7	200.11.88.211, 255.255.255.240					
8	128.1.211.33, 255.255.255.128					
9	9.211.45.65/21					
10	223.224.225.226/25					

Answers to Mask Analysis Problems

Table E-3 includes the answers to problems 1–10. The paragraphs following the table provide the explanations of each answer.

Table E-3. Answers to Problems in This Appendix



Problem Number	Problem	Network Bits	Subnet Bits	Host Bits	Number of Subnets in Network	Number of Hosts per Subnet
1	10.66.5.99, 255.255.254.0	8	15	9	$2^{15} = 32,768$	$2^9 - 2 = 510$
2	172.16.203.42, 255.255.252.0	16	6	10	$2^6 = 64$	$2^{10} - 2 = 1022$
3	192.168.55.55, 255.255.255.224	24	3	5	$2^3 = 8$	$2^5 - 2 = 30$
4	10.22.55.87/30	8	22	2	$2^{22} = 4,194,304$	$2^2 - 2 = 2$
5	172.30.40.166/26	16	10	6	$2^{10} = 1024$	$2^6 - 2 = 62$
6	192.168.203.18/29	24	5	3	$2^5 = 32$	$2^3 - 2 = 6$
7	200.11.88.211, 255.255.255.240	24	4	4	$2^4 = 16$	$2^4 - 2 = 14$
8	128.1.211.33, 255.255.255.128	16	9	7	$2^9 = 512$	$2^7 - 2 = 126$
9	9.211.45.65/21	8	13	11	$2^{13} = 8192$	$2^{11} - 2 = 2046$
10	223.224.225.226/25	24	1	7	$2^1 = 2$	$2^7 - 2 = 126$

Mask Analysis Problem 1: Answer

Address 10.66.5.99 is in Class A network 10.0.0.0, meaning that 8 network bits exist. Mask 255.255.254.0 converts to prefix /23, because the first two octets of value 255 represent 8 binary 1s, and the 254 in the third octet represents 7 binary 1s, for a total of 23 binary 1s. Therefore, the number of host bits is 32 – 23 = 9, leaving 15 subnet bits (32 – 8 network bits – 9 host bits = 15 subnet bits). The number of subnets in this Class A network, using mask 255.255.254.0, is $2^{15} = 32,768$. The number of hosts per subnet is $2^9 - 2 = 510$.

Mask Analysis Problem 2: Answer

Address 172.16.203.42, mask 255.255.252.0, is in Class B network 172.16.0.0, meaning that 16 network bits exist. Mask 255.255.252.0 converts to prefix /22, because the first two octets of value 255 represent 8 binary 1s, and the 252 in the third octet represents 6 binary 1s, for a total of 22 binary 1s. Therefore, the number of host bits is 32 – 22 = 10, leaving 6 subnet bits (32 – 16 network bits – 10 host bits = 6 subnet bits). The number of subnets in this Class B network, using mask 255.255.252.0, is $2^6 = 64$. The number of hosts per subnet is $2^{10} - 2 = 1022$.

Mask Analysis Problem 3: Answer

Address 192.168.55.55 is in Class C network 192.168.55.0, meaning that 24 network bits exist. Mask 255.255.255.224 converts to prefix /27, because the first three octets of value 255 represent 8 binary 1s, and the 224 in the fourth octet represents 3 binary 1s, for a total of 27 binary 1s. Therefore, the number of host bits is 32 – 27 = 5, leaving 3 subnet bits (32 – 24 network bits – 5 host bits = 3 subnet bits). The number of subnets in this Class C network, using mask 255.255.255.224, is $2^3 = 8$. The number of hosts per subnet is $2^5 - 2 = 30$.

Mask Analysis Problem 4: Answer

Address 10.22.55.87 is in Class A network 10.0.0.0, meaning that 8 network bits exist. The prefix format mask of /30 lets you calculate the number of host bits as 32 – prefix length (in this case, 32 – 30 = 2). This leaves 22 subnet bits (32 – 8 network bits – 2 host bits = 22 subnet bits). The number of subnets in this Class A network, using mask 255.255.255.252, is $2^{22} = 4,194,304$. The number of hosts per subnet is $2^2 - 2 = 2$. (Note that this mask is popularly used on serial links, which need only two IP addresses in a subnet.)

Mask Analysis Problem 5: Answer

Address 172.30.40.166 is in Class B network 172.30.0.0, meaning that 16 network bits exist. The prefix format mask of /26 lets you calculate the number of host bits as 32 – prefix length (in this case, 32 – 26 = 6). This leaves 10 subnet bits (32 – 16 network bits – 6 host bits = 10 subnet bits). The number of subnets in this Class B network, using mask /26, is 2^{10} = 1024. The number of hosts per subnet is 2^6 – 2 = 62.

Mask Analysis Problem 6: Answer

Address 192.168.203.18 is in Class C network 192.168.203.0, meaning that 24 network bits exist. The prefix format mask of /29 lets you calculate the number of host bits as 32 – prefix length (in this case, 32 – 29 = 3). This leaves 5 subnet bits, because 32 – 24 network bits – 3 host bits = 5 subnet bits. The number of subnets in this Class C network, using mask /29, is 2^5 = 32. The number of hosts per subnet is 2^3 – 2 = 6.

Mask Analysis Problem 7: Answer

Address 200.11.88.211 is in Class C network 200.11.88.0, meaning that 24 network bits exist. Mask 255.255.255.240 converts to prefix /28, because the first three octets of value 255 represent 8 binary 1s, and the 240 in the fourth octet represents 4 binary 1s, for a total of 28 binary 1s. This leaves 4 subnet bits (32 – 24 network bits – 4 host bits = 4 subnet bits). The number of subnets in this Class C network, using mask /28, is 2^4 = 16. The number of hosts per subnet is 2^4 – 2 = 14.

Mask Analysis Problem 8: Answer

Address 128.1.211.33, mask 255.255.255.128, is in Class B network 128.1.0.0, meaning that 16 network bits exist. Mask 255.255.255.128 converts to prefix /25, because the first three octets of value 255 represent 8 binary 1s, and the 128 in the fourth octet represents 1 binary 1, for a total of 25 binary 1s. Therefore, the number of host bits is 32 – 25 = 7, leaving 9 subnet bits (32 – 16 network bits – 7 host bits = 9 subnet bits). The number of subnets in this Class B network, using mask 255.255.255.128, is 2^9 = 512. The number of hosts per subnet is 2^7 – 2 = 126.

Mask Analysis Problem 9: Answer

Address 9.211.45.65 is in Class A network 10.0.0.0, meaning that 8 network bits exist. The prefix format mask of /21 lets you calculate the number of host bits as 32 – prefix length (in this case, 32 – 21 = 11). This leaves 13 subnet bits (32 – 8 network bits – 11 host bits = 13 subnet bits). The number of subnets in this Class A network, using mask /21, is 2^{13} = 8192. The number of hosts per subnet is 2^{11} – 2 = 2046.

Mask Analysis Problem 10: Answer

Address 223.224.225.226 is in Class C network 223.224.225.0, meaning that 24 network bits exist. The prefix format mask of /25 lets you calculate the number of host bits as 32 – prefix length (in this case, 32 – 25 = 7). This leaves 1 subnet bit (32 – 24 network bits – 7 host bits = 1 subnet bit). The number of subnets in this Class C network, using mask /25, is 2^1 = 2. The number of hosts per subnet is 2^7 – 2 = 126.

Appendix F. Practice for Chapter 14: Analyzing Existing Subnets

Practice Problems

This appendix lists practice problems related to Chapter 14, "Analyzing Existing Subnets." Each problem asks you to find a variety of information about the subnet in which an IP address resides. Each problem supplies an IP address and a subnet mask, from which you should find the following information:

- Subnet number
- Subnet broadcast address
- Range of valid IP addresses in this network

To find these facts, you can use any of the processes explained in Chapter 14 of the *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*.

Additionally, these same problems can be used to review the concepts in Chapter 13, "Analyzing Subnet Masks." To use these same problems for practice related to Chapter 13, simply find the following information for each of the problems:

- Size of the network part of the address
- Size of the subnet part of the address
- Size of the host part of the address
- Number of hosts per subnet
- Number of subnets in this network

Feel free to either ignore or use the opportunity for more practice related to analyzing subnet masks.

Solve for the following problems:

1. 10.180.10.18, mask 255.192.0.0
2. 10.200.10.18, mask 255.224.0.0
3. 10.100.18.18, mask 255.240.0.0
4. 10.100.18.18, mask 255.248.0.0
5. 10.150.200.200, mask 255.252.0.0
6. 10.150.200.200, mask 255.254.0.0
7. 10.220.100.18, mask 255.255.0.0
8. 10.220.100.18, mask 255.255.128.0
9. 172.31.100.100, mask 255.255.192.0
10. 172.31.100.100, mask 255.255.224.0
11. 172.31.200.10, mask 255.255.240.0
12. 172.31.200.10, mask 255.255.248.0
13. 172.31.50.50, mask 255.255.252.0
14. 172.31.50.50, mask 255.255.254.0
15. 172.31.140.14, mask 255.255.255.0
16. 172.31.140.14, mask 255.255.255.128
17. 192.168.15.150, mask 255.255.255.192
18. 192.168.15.150, mask 255.255.255.224
19. 192.168.100.100, mask 255.255.255.240
20. 192.168.100.100, mask 255.255.255.248
21. 192.168.15.230, mask 255.255.255.252
22. 10.1.1.1, mask 255.248.0.0
23. 172.16.1.200, mask 255.255.240.0
24. 172.16.0.200, mask 255.255.255.192
25. 10.1.1.1, mask 255.0.0.0

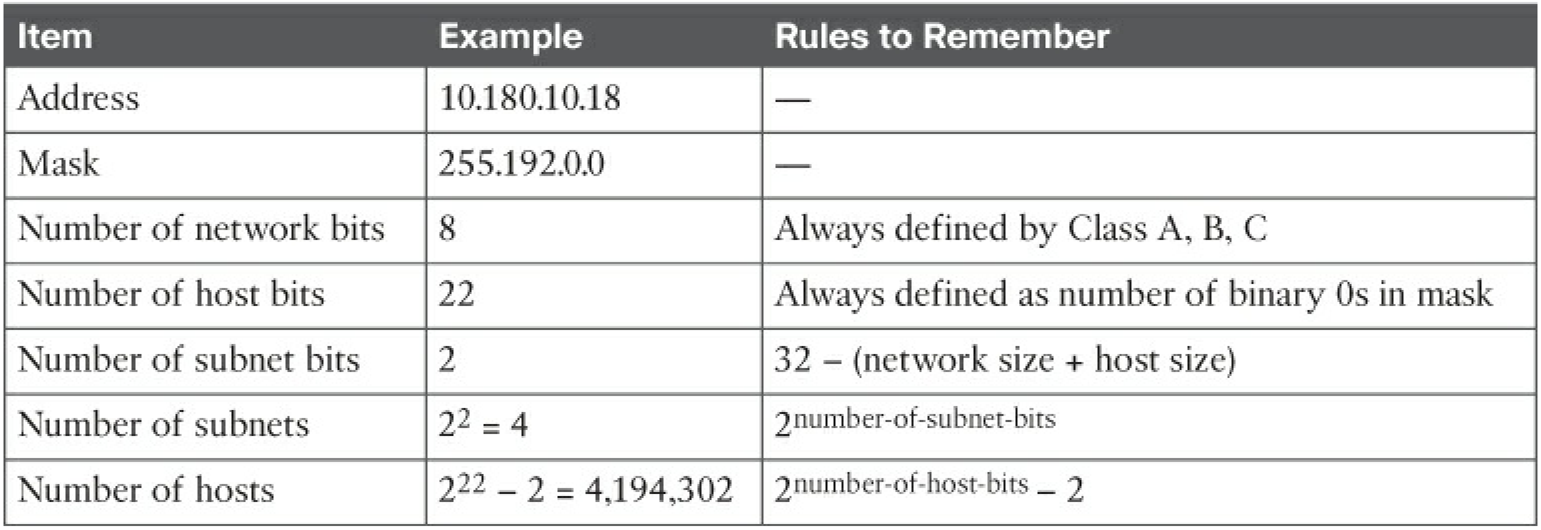
Answers

This section includes the answers to the 25 problems listed in this appendix. The answer section for each problem explains how to use the process outlined in Chapter 14 to find the answers. Also, refer to Chapter 13 for details on how to find information about analyzing the subnet mask.

Answer to Problem 1

The answers begin with the analysis of the three parts of the address, the number of hosts per subnet, and the number of subnets of this network using the stated mask, as outlined in Table F-1. The binary math for subnet and broadcast address calculation follows. The answer finishes with the easier mental calculations for the range of IP addresses in the subnet.

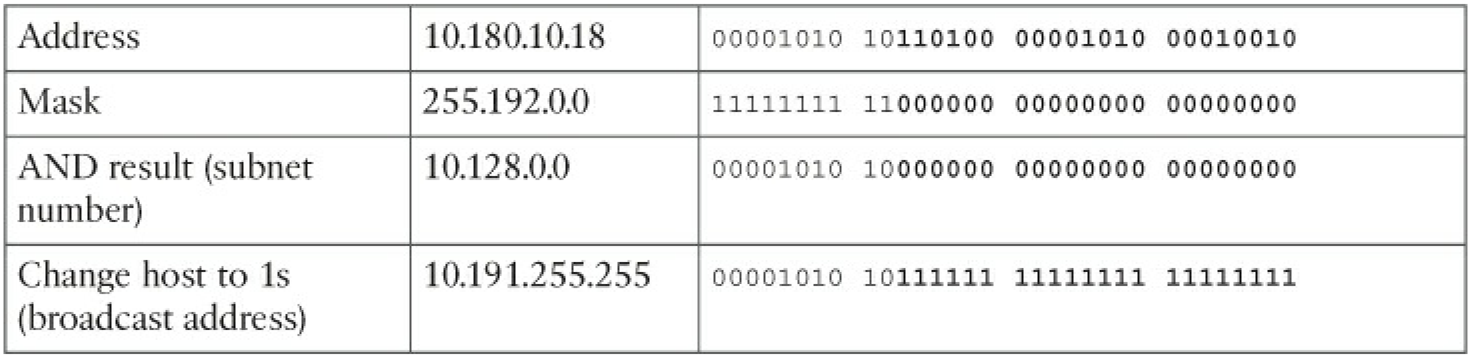
Table F-1. Question 1: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	10.180.10.18	—
Mask	255.192.0.0	—
Number of network bits	8	Always defined by Class A, B, C
Number of host bits	22	Always defined as number of binary 0s in mask
Number of subnet bits	2	32 – (network size + host size)
Number of subnets	$2^2 = 4$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^{22} - 2 = 4{,}194{,}302$	$2^{\text{number-of-host-bits}} - 2$

Table F-2 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-2. Question 1: Binary Calculation of Subnet and Broadcast Addresses



Address	10.180.10.18	00001010 10**110100** **00001010** **00010010**
Mask	255.192.0.0	11111111 11**000000** **00000000** **00000000**
AND result (subnet number)	10.128.0.0	00001010 10**000000** **00000000** **00000000**
Change host to 1s (broadcast address)	10.191.255.255	00001010 10**111111** **11111111** **11111111**

To get the first valid IP address, just add 1 to the subnet number; to get the last valid IP address, just subtract 1 from the broadcast address. In this case:

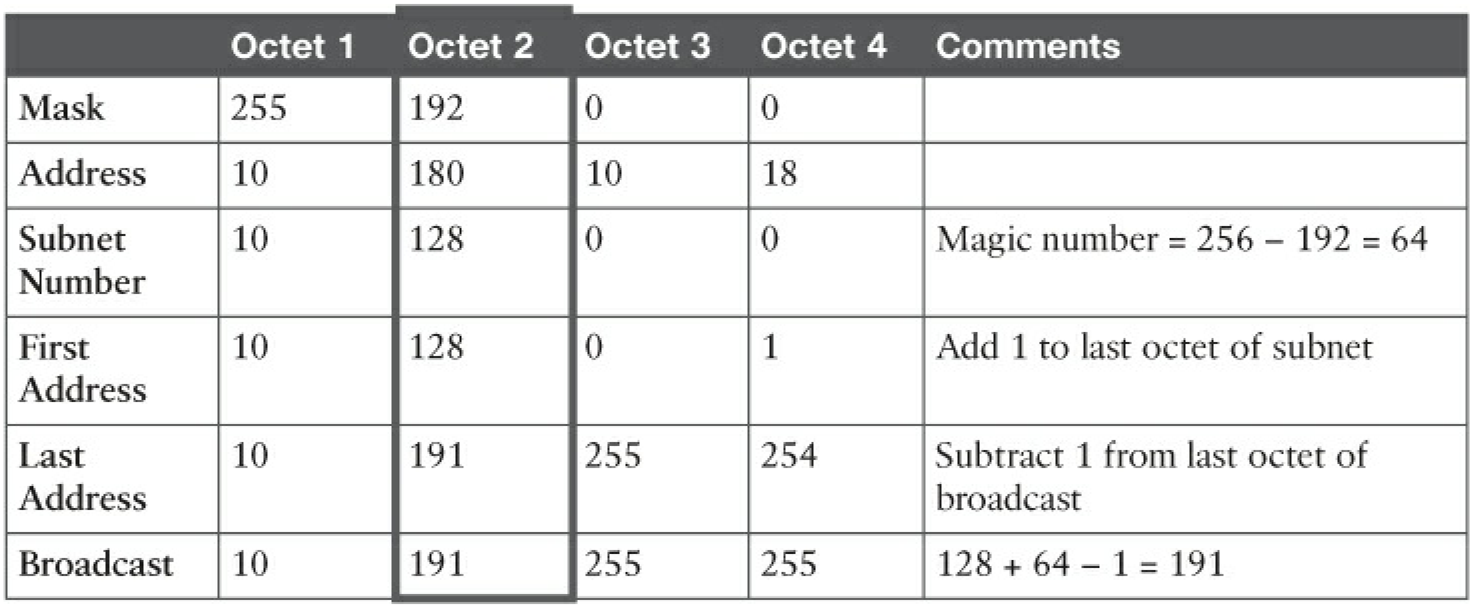
10.128.0.1 through 10.191.255.254
10.128.0.0 + 1 = 10.128.0.1
10.191.255.255 – 1 = 10.191.255.254

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. The key parts of the process are as follows:

- The interesting octet is the octet for which the mask's value is not a decimal 0 or 255.
- The magic number is calculated as the value of the IP address's interesting octet, subtracted from 256.
- The subnet number can be found by copying the IP address octets to the left of the interesting octet, by writing down 0s for octets to the right of the interesting octet, and by finding the multiple of the magic number closest to, but not larger than, the IP address's value in that same octet.
- The broadcast address can be similarly found by coping the subnet number's octets to the left of the interesting octet, by writing 255s for octets to the right of the interesting octet, and by taking the subnet number's value in the interesting octet, adding the magic number, and subtracting 1.

Table F-3 shows the work for this problem, with some explanation of the work following the table. Refer to Chapter 14 for the detailed processes.

Table F-3. Question 1: Subnet, Broadcast, and First and Last Addresses Calculated Using the Decimal Process



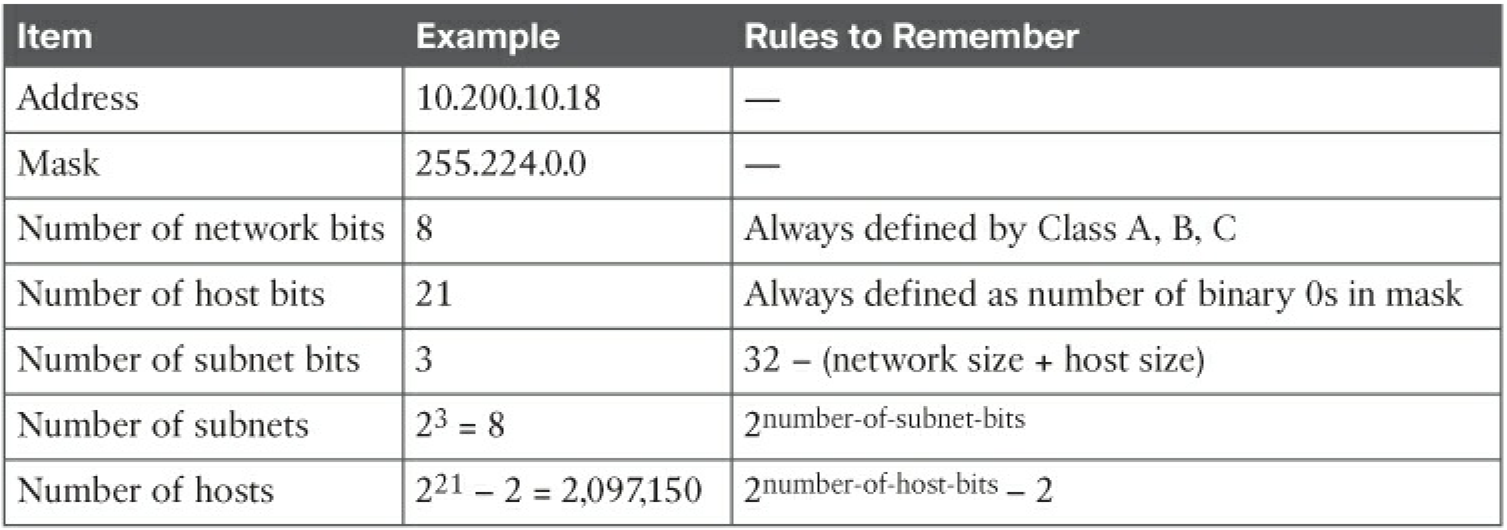
	Octet 1	Octet 2	Octet 3	Octet 4	Comments
Mask	255	192	0	0	
Address	10	180	10	18	
Subnet Number	10	128	0	0	Magic number = 256 – 192 = 64
First Address	10	128	0	1	Add 1 to last octet of subnet
Last Address	10	191	255	254	Subtract 1 from last octet of broadcast
Broadcast	10	191	255	255	128 + 64 – 1 = 191

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The second octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 192 = 64 in this case (256 – mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 128 is the multiple of 64 that is closest to 180 but not higher than 180. So, the second octet of the subnet number is 128.

The second part of this process calculates the subnet broadcast address, with the tricky part, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 128 + 64 – 1 = 191.

Answer to Problem 2

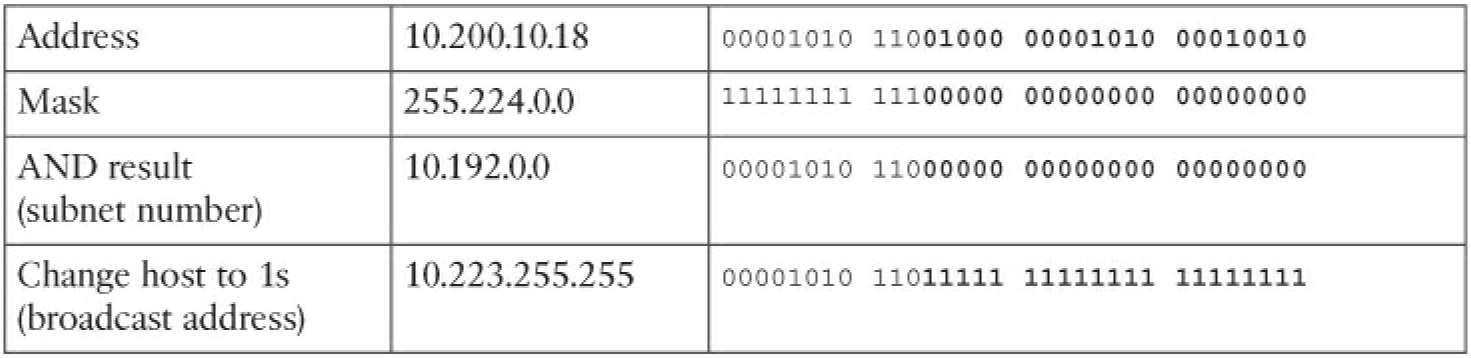
Table F-4. Question 2: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	10.200.10.18	—
Mask	255.224.0.0	—
Number of network bits	8	Always defined by Class A, B, C
Number of host bits	21	Always defined as number of binary 0s in mask
Number of subnet bits	3	32 – (network size + host size)
Number of subnets	$2^3 = 8$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^{21} - 2 = 2{,}097{,}150$	$2^{\text{number-of-host-bits}} - 2$

Table F-5 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-5. Question 2: Binary Calculation of Subnet and Broadcast Addresses



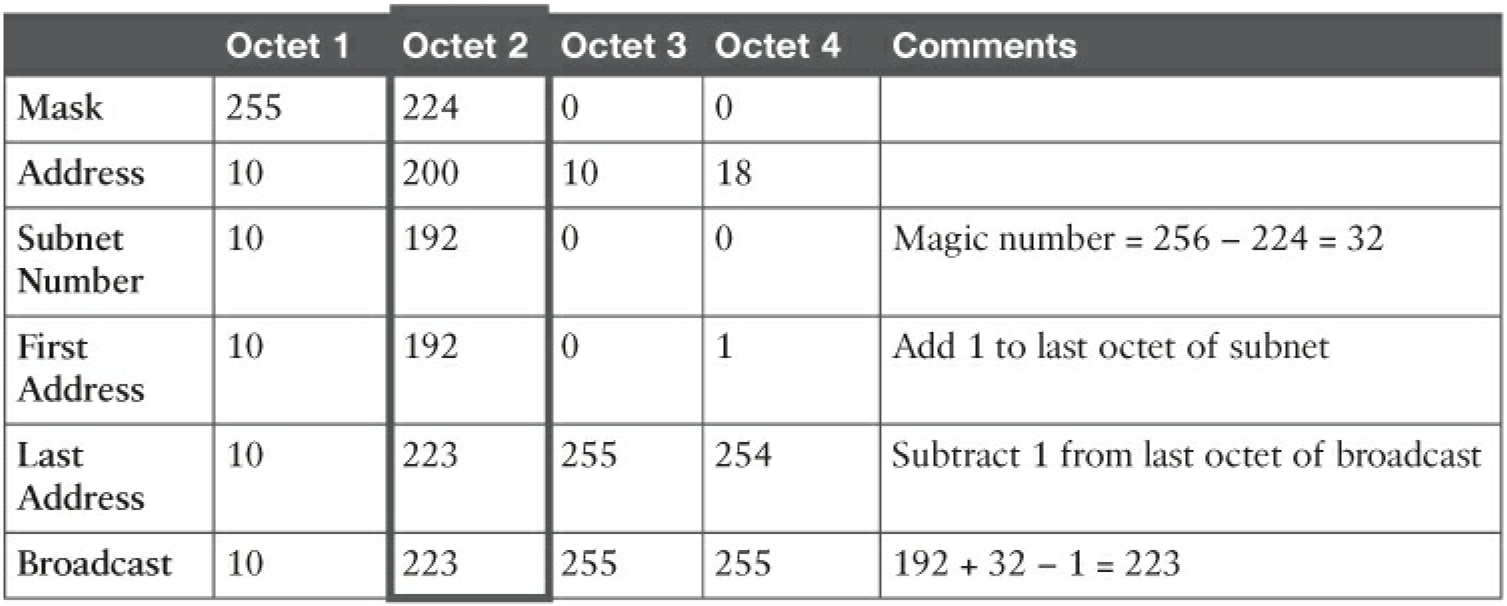
Address	10.200.10.18	00001010 110**01000** **00001010** **00010010**
Mask	255.224.0.0	11111111 111**00000** **00000000** **00000000**
AND result (subnet number)	10.192.0.0	00001010 110**00000** **00000000** **00000000**
Change host to 1s (broadcast address)	10.223.255.255	00001010 110**11111** **11111111** **11111111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

10.192.0.1 through 10.223.255.254

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-6 shows the work for this problem, with some explanation of the work following the table.

Table F-6. Question 2: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart



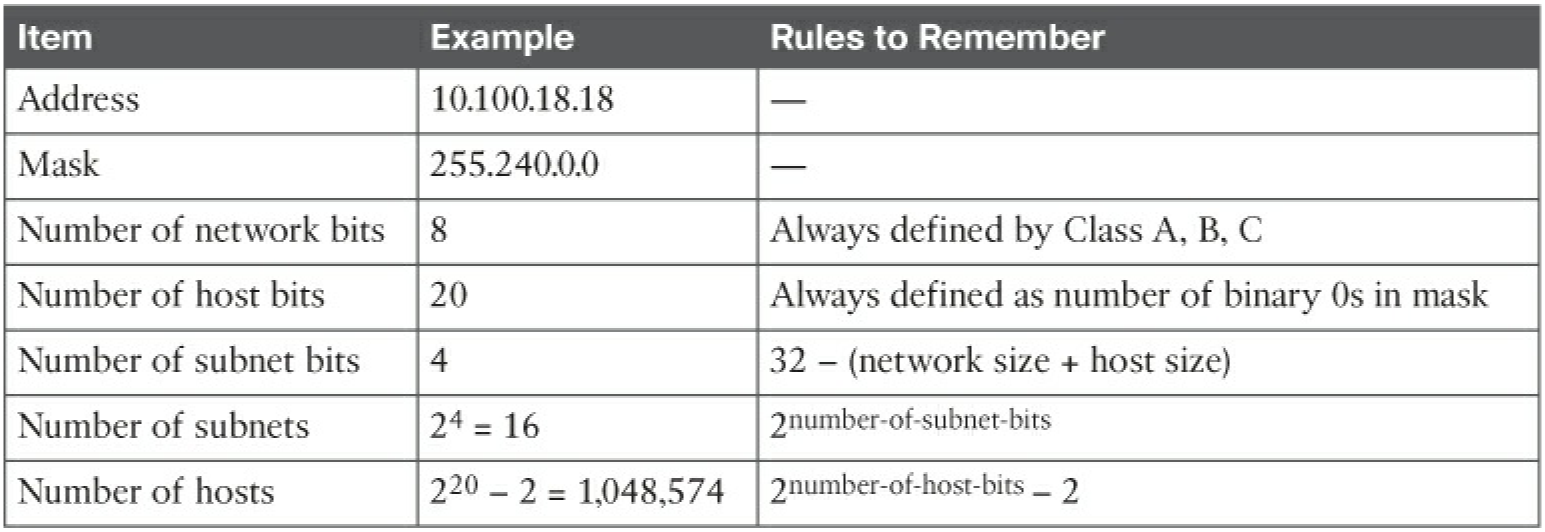
	Octet 1	Octet 2	Octet 3	Octet 4	Comments
Mask	255	224	0	0	
Address	10	200	10	18	
Subnet Number	10	192	0	0	Magic number = 256 – 224 = 32
First Address	10	192	0	1	Add 1 to last octet of subnet
Last Address	10	223	255	254	Subtract 1 from last octet of broadcast
Broadcast	10	223	255	255	192 + 32 – 1 = 223

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The second octet is “interesting” in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 224 = 32 in this case (256 – mask’s value in the interesting octet). The subnet number’s value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address’s value in the interesting octet. In this case, 192 is the multiple of 32 that is closest to 200 but not higher than 200. So, the second octet of the subnet number is 192.

The second part of this process calculates the subnet broadcast address, with the tricky part, as usual, in the “interesting” octet. Take the subnet number’s value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address’s value in the interesting octet. In this case, it is 192 + 32 – 1 = 223.

Answer to Problem 3

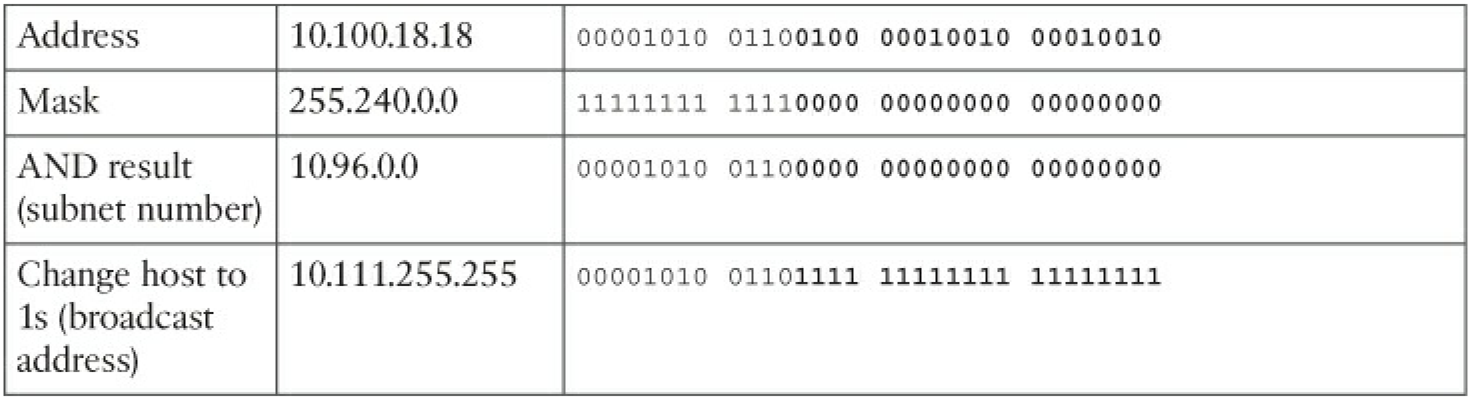
Table F-7. Question 3: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	10.100.18.18	—
Mask	255.240.0.0	—
Number of network bits	8	Always defined by Class A, B, C
Number of host bits	20	Always defined as number of binary 0s in mask
Number of subnet bits	4	32 – (network size + host size)
Number of subnets	$2^4 = 16$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^{20} - 2 = 1,048,574$	$2^{\text{number-of-host-bits}} - 2$

Table F-8 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-8. Question 3: Binary Calculation of Subnet and Broadcast Addresses



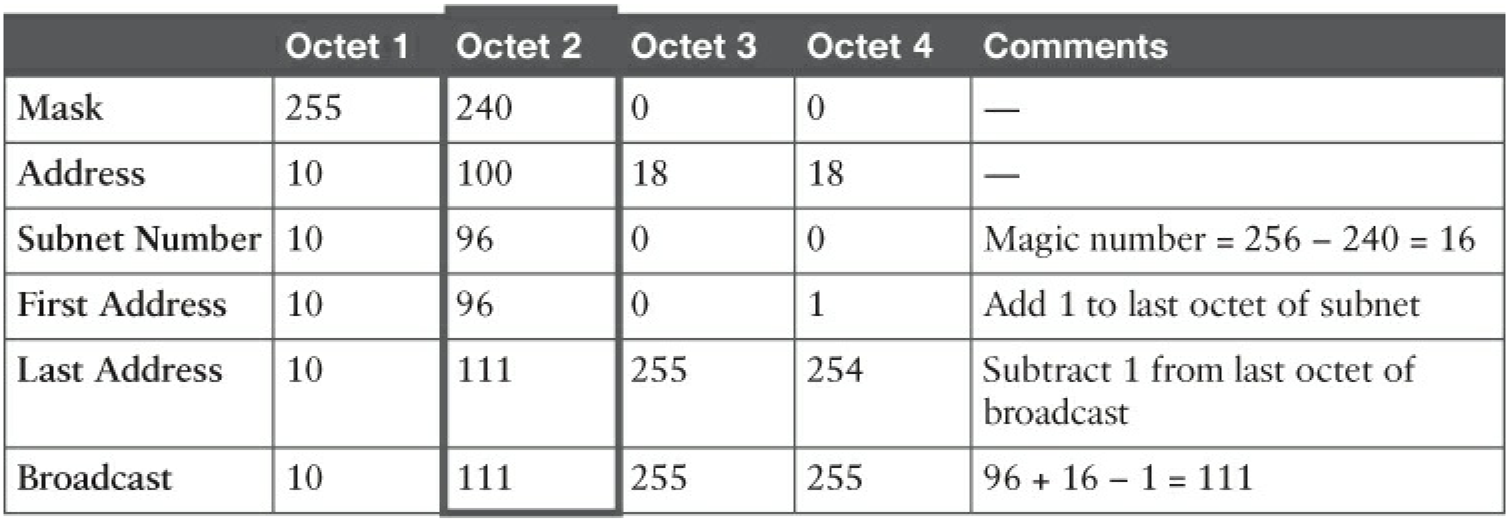
Address	10.100.18.18	00001010 01100100 00010010 00010010
Mask	255.240.0.0	11111111 11110000 00000000 00000000
AND result (subnet number)	10.96.0.0	00001010 01100000 00000000 00000000
Change host to 1s (broadcast address)	10.111.255.255	00001010 01101111 11111111 11111111

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

10.96.0.1 through 10.111.255.254

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-9 shows the work for this problem, with some explanation of the work following the table.

Table F-9. Question 3: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart



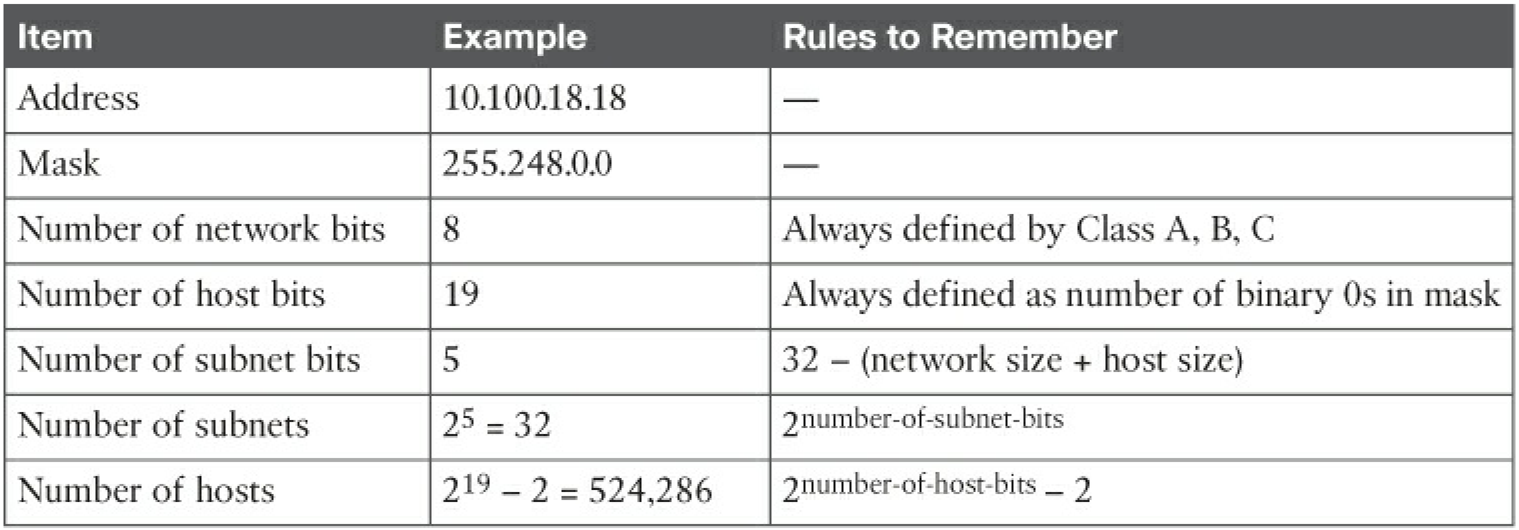
	Octet 1	Octet 2	Octet 3	Octet 4	Comments
Mask	255	240	0	0	—
Address	10	100	18	18	—
Subnet Number	10	96	0	0	Magic number = 256 – 240 = 16
First Address	10	96	0	1	Add 1 to last octet of subnet
Last Address	10	111	255	254	Subtract 1 from last octet of broadcast
Broadcast	10	111	255	255	96 + 16 – 1 = 111

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The second octet is “interesting” in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 240 = 16 in this case (256 – mask’s value in the interesting octet). The subnet number’s value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address’s value in the interesting octet. In this case, 96 is the multiple of 16 that is closest to 100 but not higher than 100. So, the second octet of the subnet number is 96.

The second part of this process calculates the subnet broadcast address, with the tricky part, as usual, in the “interesting” octet. Take the subnet number’s value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address’s value in the interesting octet. In this case, it is 96 + 16 – 1 = 111.

Answer to Problem 4

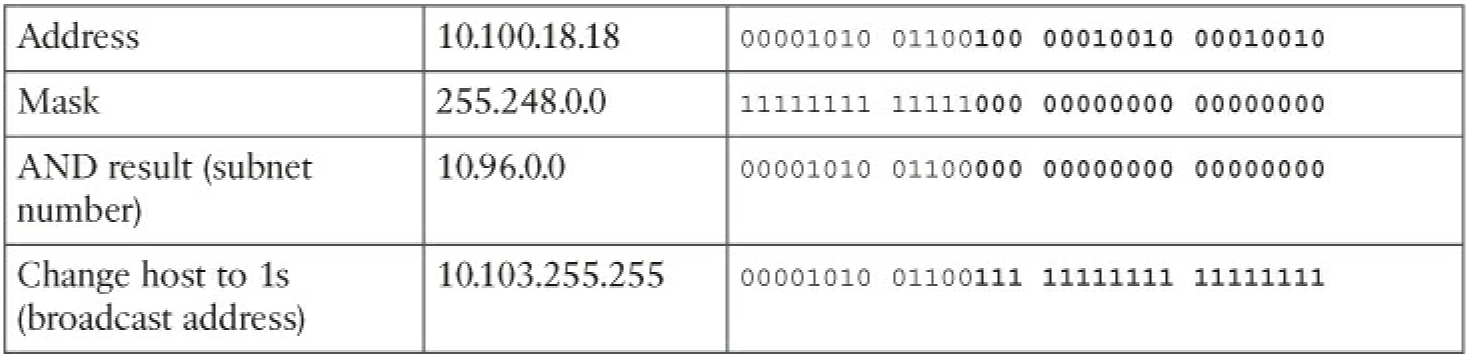
Table F-10. Question 4: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	10.100.18.18	—
Mask	255.248.0.0	—
Number of network bits	8	Always defined by Class A, B, C
Number of host bits	19	Always defined as number of binary 0s in mask
Number of subnet bits	5	32 – (network size + host size)
Number of subnets	$2^5 = 32$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^{19} - 2 = 524,286$	$2^{\text{number-of-host-bits}} - 2$

Table F-11 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-11. Question 4: Binary Calculation of Subnet and Broadcast Addresses



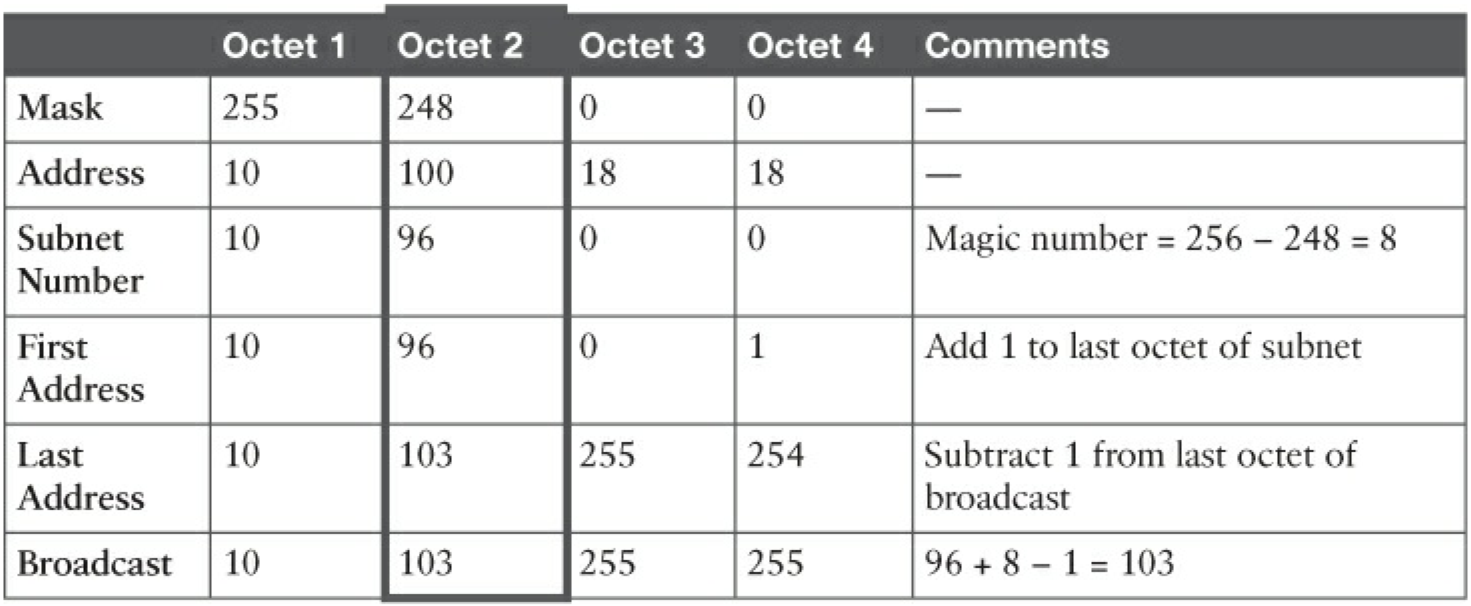
Address	10.100.18.18	00001010 01100**100 00010010 00010010**
Mask	255.248.0.0	11111111 11111**000 00000000 00000000**
AND result (subnet number)	10.96.0.0	00001010 01100**000 00000000 00000000**
Change host to 1s (broadcast address)	10.103.255.255	00001010 01100**111 11111111 11111111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

10.96.0.1 through 10.103.255.254

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-12 shows the work for this problem, with some explanation of the work following the table.

Table F-12. Question 4: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart



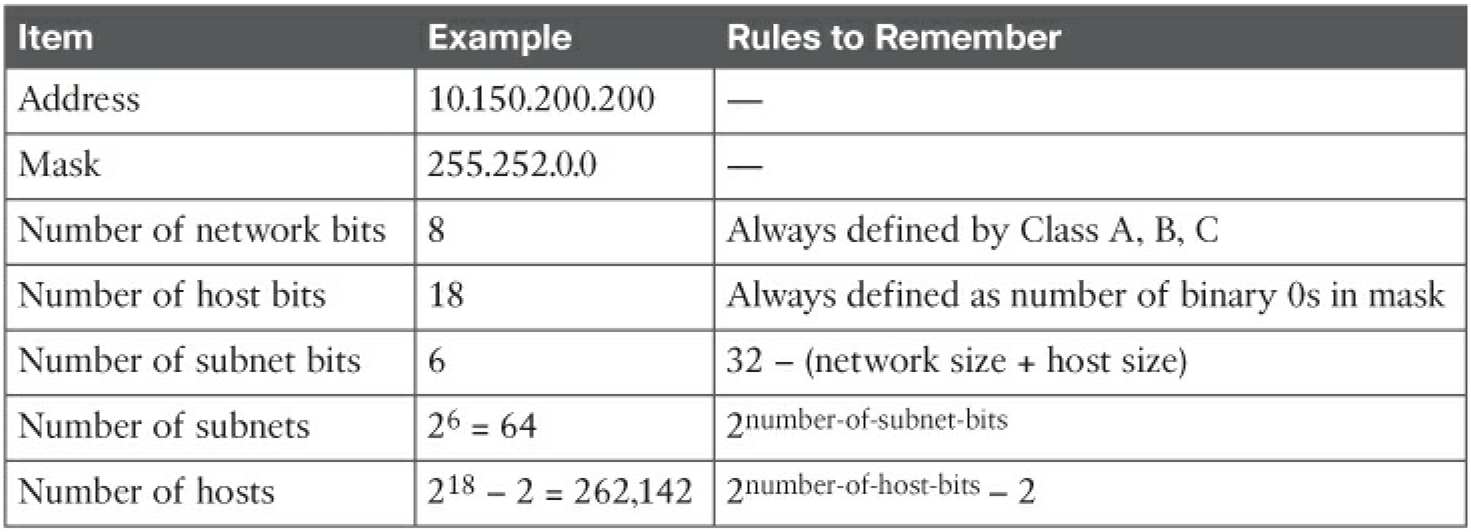
	Octet 1	Octet 2	Octet 3	Octet 4	Comments
Mask	255	248	0	0	—
Address	10	100	18	18	—
Subnet Number	10	96	0	0	Magic number = 256 – 248 = 8
First Address	10	96	0	1	Add 1 to last octet of subnet
Last Address	10	103	255	254	Subtract 1 from last octet of broadcast
Broadcast	10	103	255	255	96 + 8 – 1 = 103

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The second octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 248 = 8 in this case (256 – mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 96 is the multiple of 8 that is closest to 100 but not higher than 100. So, the second octet of the subnet number is 96.

The second part of this process calculates the subnet broadcast address with the tricky part, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 96 + 8 – 1 = 103.

Answer to Problem 5

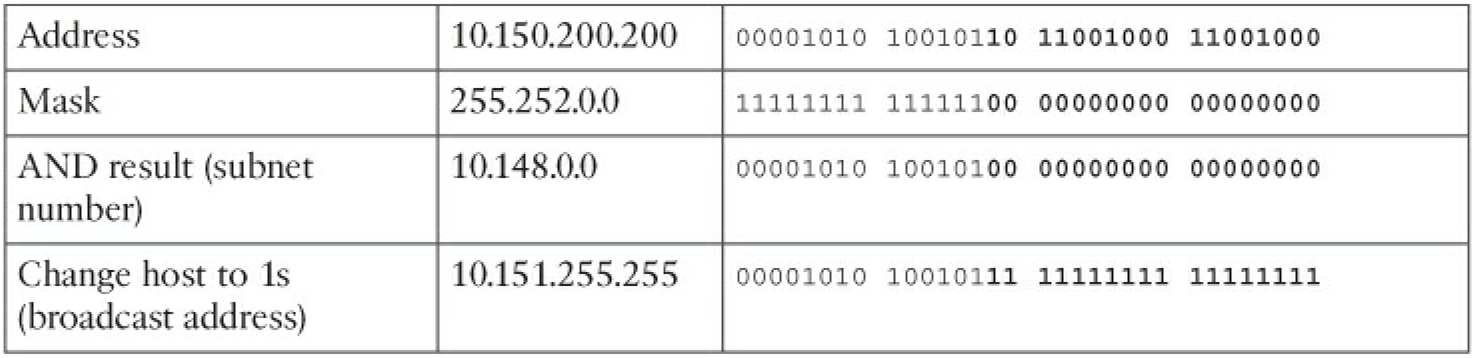
Table F-13. Question 5: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	10.150.200.200	—
Mask	255.252.0.0	—
Number of network bits	8	Always defined by Class A, B, C
Number of host bits	18	Always defined as number of binary 0s in mask
Number of subnet bits	6	32 – (network size + host size)
Number of subnets	$2^6 = 64$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^{18} - 2 = 262,142$	$2^{\text{number-of-host-bits}} - 2$

Table F-14 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-14. Question 5: Binary Calculation of Subnet and Broadcast Addresses



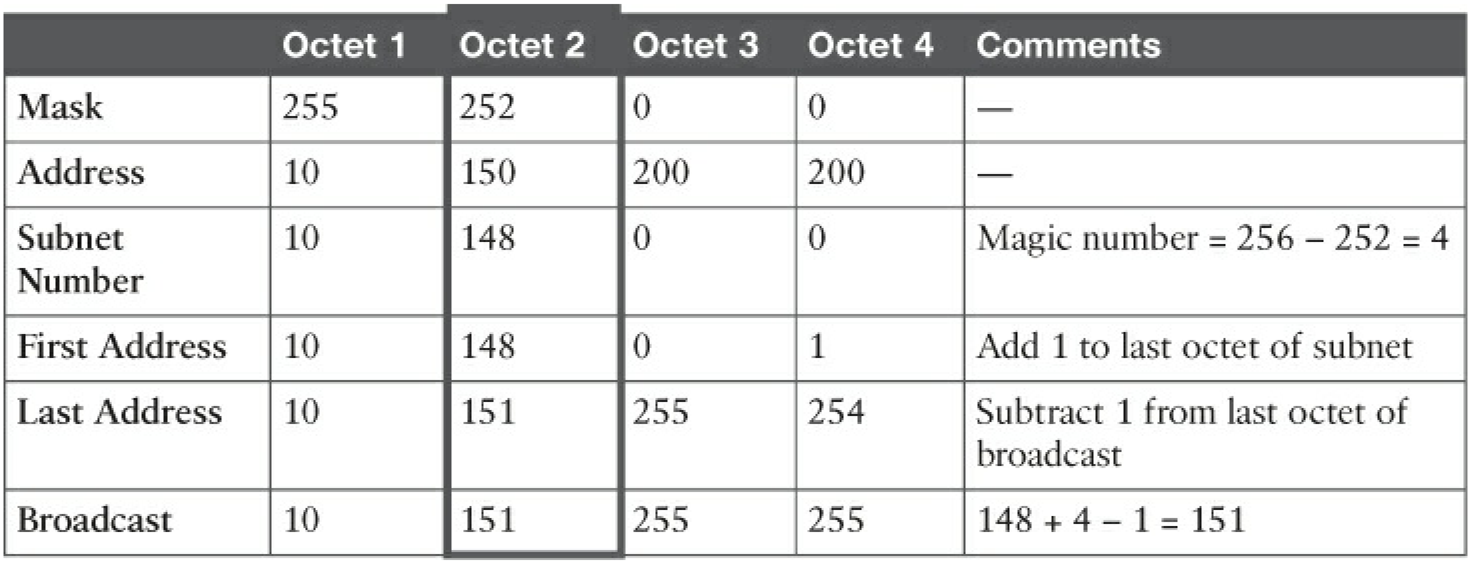
Address	10.150.200.200	00001010 100101**10** **11001000** **11001000**
Mask	255.252.0.0	11111111 111111**00** **00000000** **00000000**
AND result (subnet number)	10.148.0.0	00001010 100101**00** **00000000** **00000000**
Change host to 1s (broadcast address)	10.151.255.255	00001010 100101**11** **11111111** **11111111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

10.148.0.1 through 10.151.255.254

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-15 shows the work for this problem, with some explanation of the work following the table.

Table F-15. Question 5: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart



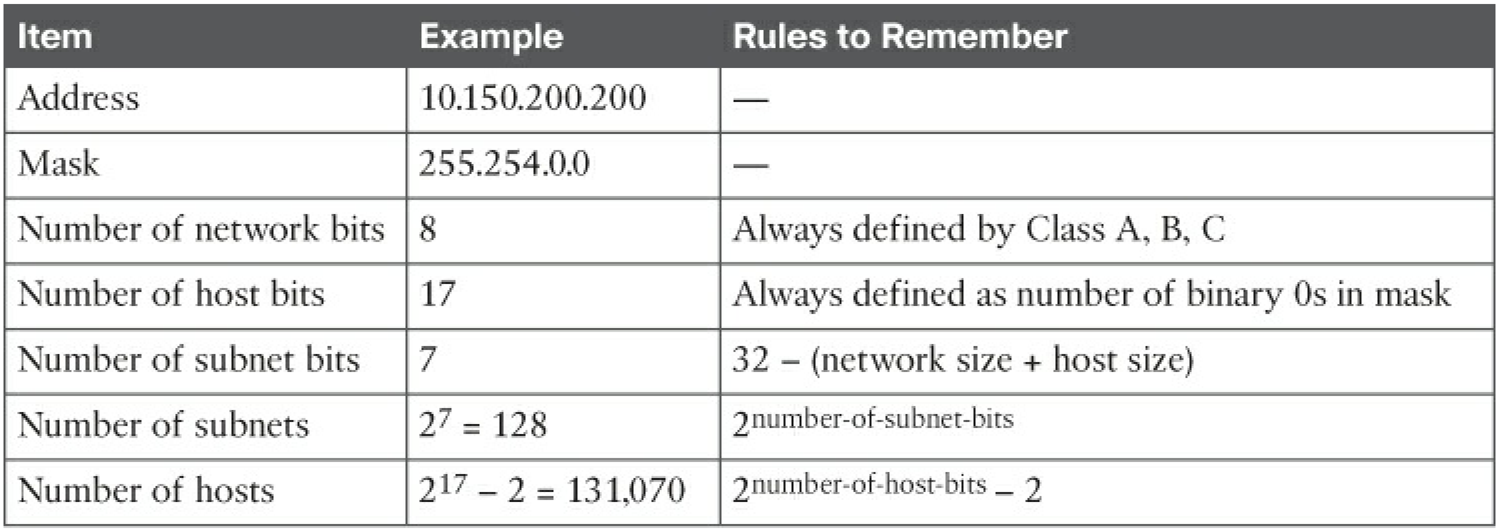
	Octet 1	Octet 2	Octet 3	Octet 4	Comments
Mask	255	252	0	0	—
Address	10	150	200	200	—
Subnet Number	10	148	0	0	Magic number = 256 – 252 = 4
First Address	10	148	0	1	Add 1 to last octet of subnet
Last Address	10	151	255	254	Subtract 1 from last octet of broadcast
Broadcast	10	151	255	255	148 + 4 – 1 = 151

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The second octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 252 = 4 in this case (256 – mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 148 is the multiple of 4 that is closest to 150 but not higher than 150. So, the second octet of the subnet number is 148.

The second part of this process calculates the subnet broadcast address with the tricky part, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 148 + 4 – 1 = 151.

Answer to Problem 6

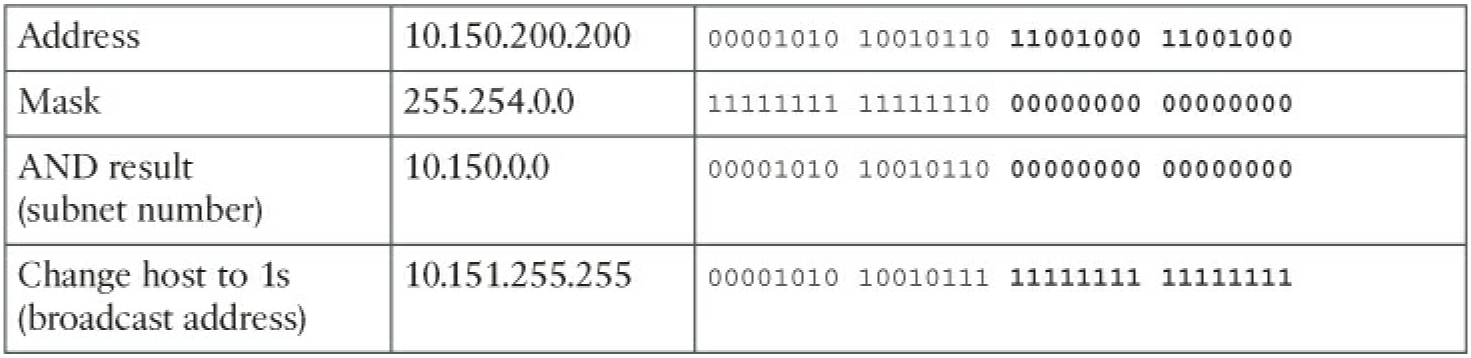
Table F-16. Question 6: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	10.150.200.200	—
Mask	255.254.0.0	—
Number of network bits	8	Always defined by Class A, B, C
Number of host bits	17	Always defined as number of binary 0s in mask
Number of subnet bits	7	32 – (network size + host size)
Number of subnets	$2^7 = 128$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^{17} - 2 = 131{,}070$	$2^{\text{number-of-host-bits}} - 2$

Table F-17 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-17. Question 6: Binary Calculation of Subnet and Broadcast Addresses



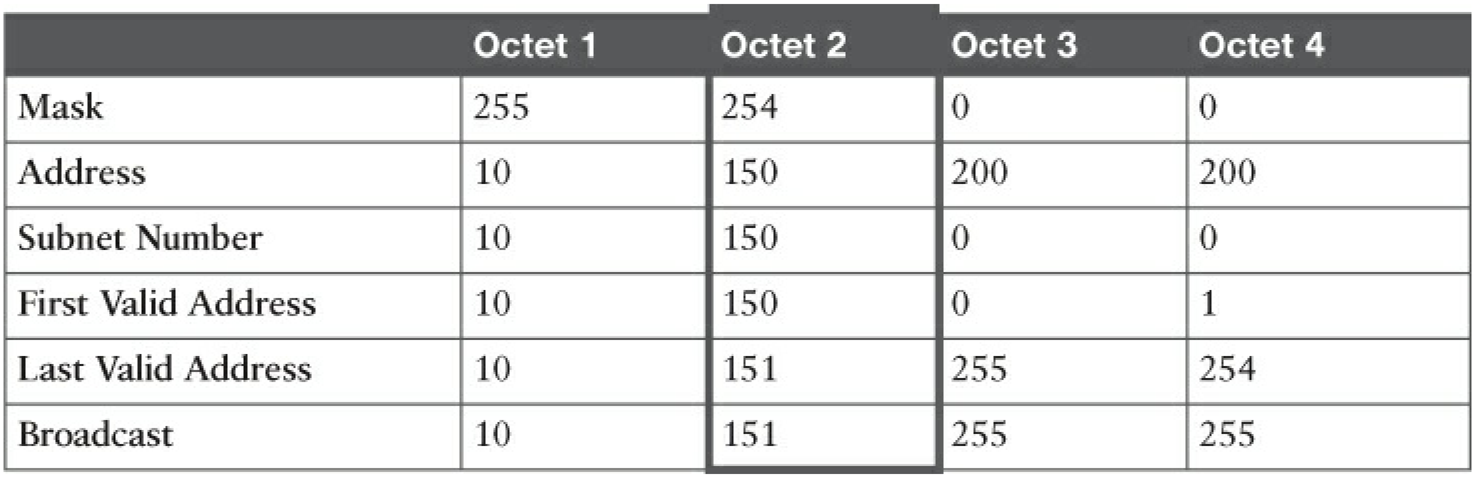
Address	10.150.200.200	00001010 10010110 **11001000 11001000**
Mask	255.254.0.0	11111111 11111110 **00000000 00000000**
AND result (subnet number)	10.150.0.0	00001010 10010110 **00000000 00000000**
Change host to 1s (broadcast address)	10.151.255.255	00001010 10010111 **11111111 11111111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

10.150.0.1 through 10.151.255.254

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-18 shows the work for this problem, with some explanation of the work following the table.

Table F-18. Question 6: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart



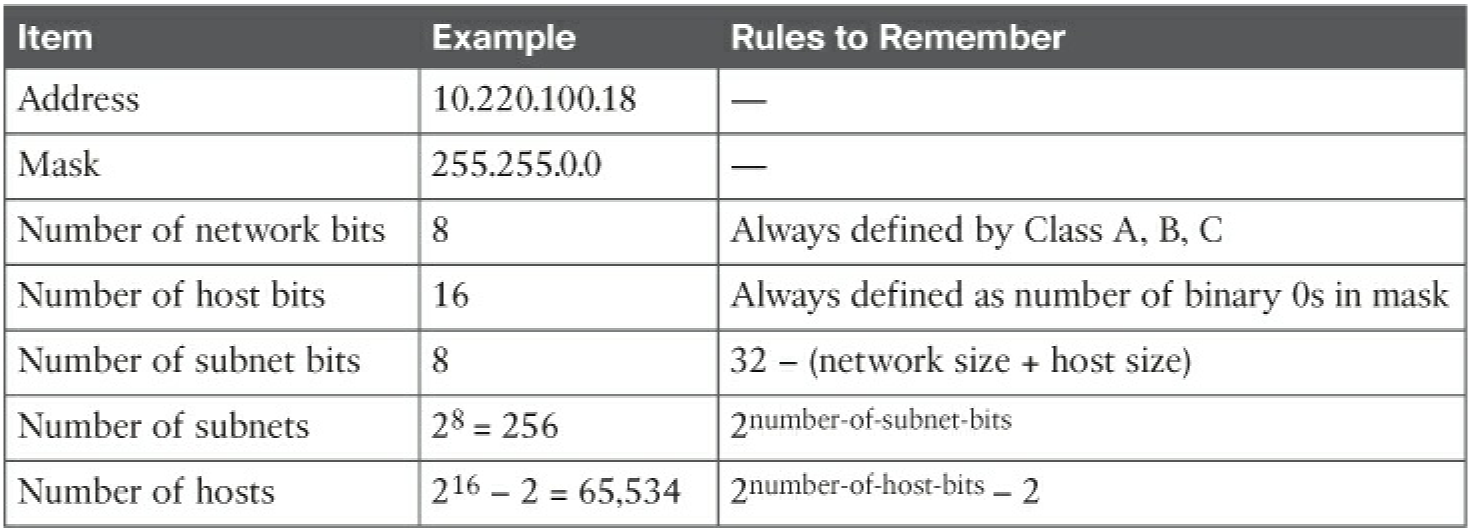
	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	254	0	0
Address	10	150	200	200
Subnet Number	10	150	0	0
First Valid Address	10	150	0	1
Last Valid Address	10	151	255	254
Broadcast	10	151	255	255

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The second octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 254 = 2 in this case (256 – mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 150 is the multiple of 2 that is closest to 150 but not higher than 150. So, the second octet of the subnet number is 150.

The second part of this process calculates the subnet broadcast address with the tricky part, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 150 + 2 – 1 = 151.

Answer to Problem 7

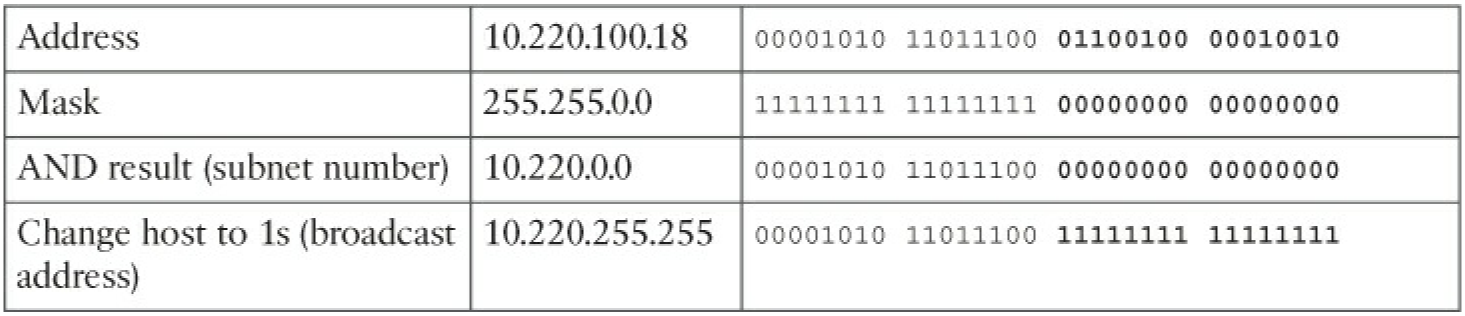
Table F-19. Question 7: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	10.220.100.18	—
Mask	255.255.0.0	—
Number of network bits	8	Always defined by Class A, B, C
Number of host bits	16	Always defined as number of binary 0s in mask
Number of subnet bits	8	32 – (network size + host size)
Number of subnets	$2^8 = 256$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^{16} - 2 = 65{,}534$	$2^{\text{number-of-host-bits}} - 2$

Table F-20 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-20. Question 7: Binary Calculation of Subnet and Broadcast Addresses



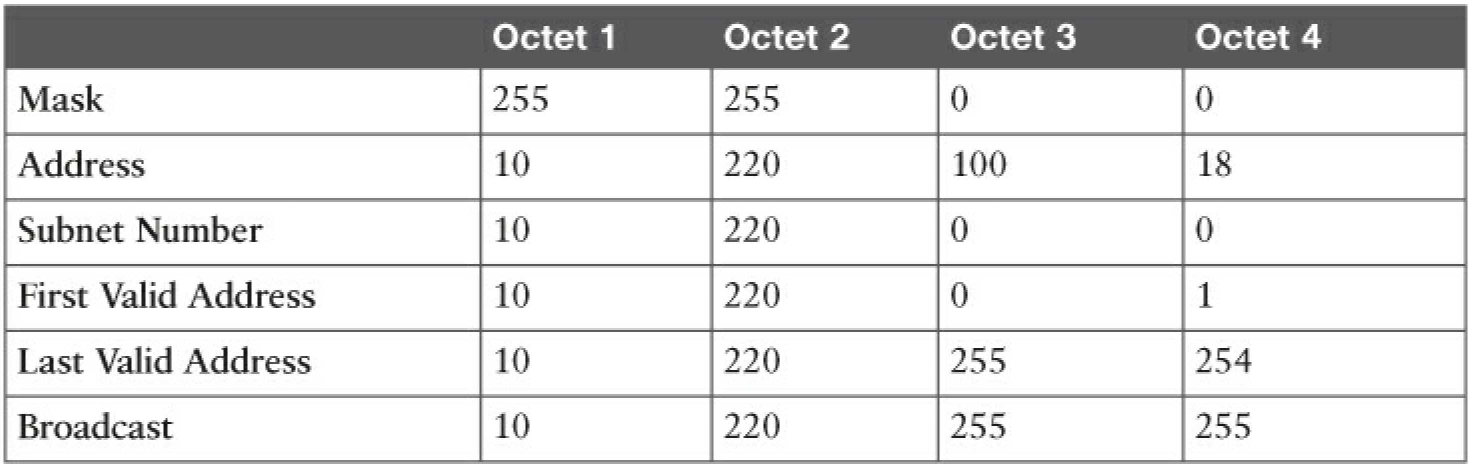
Address	10.220.100.18	00001010 11011100 **01100100 00010010**
Mask	255.255.0.0	11111111 11111111 **00000000 00000000**
AND result (subnet number)	10.220.0.0	00001010 11011100 **00000000 00000000**
Change host to 1s (broadcast address)	10.220.255.255	00001010 11011100 **11111111 11111111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

10.220.0.1 through 10.220.255.254

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-21 shows the work for this problem.

Table F-21. Question 7: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart

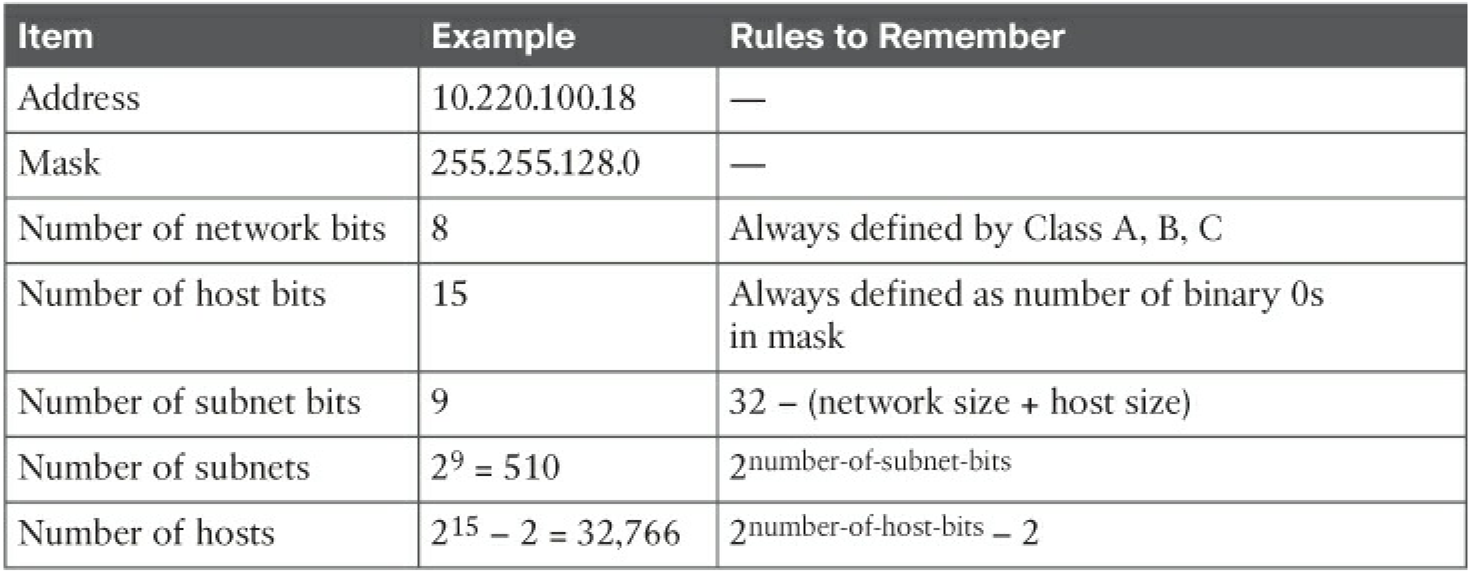


	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	255	0	0
Address	10	220	100	18
Subnet Number	10	220	0	0
First Valid Address	10	220	0	1
Last Valid Address	10	220	255	254
Broadcast	10	220	255	255

This subnetting scheme uses an easy mask because all the octets are a 0 or a 255. No math tricks are needed.

Answer to Problem 8

Table F-22. Question 8: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	10.220.100.18	—
Mask	255.255.128.0	—
Number of network bits	8	Always defined by Class A, B, C
Number of host bits	15	Always defined as number of binary 0s in mask
Number of subnet bits	9	32 – (network size + host size)
Number of subnets	$2^9 = 510$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^{15} - 2 = 32,766$	$2^{\text{number-of-host-bits}} - 2$

Table F-23 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-23. Question 8: Binary Calculation of Subnet and Broadcast Addresses

Address	10.220.100.18	00001010 11011100 01100100 00010010
Mask	255.255.128.0	11111111 11111111 10000000 00000000
AND result (subnet number)	10.220.0.0	00001010 11011100 00000000 00000000
Change host to 1s (broadcast address)	10.220.127.255	00001010 11011100 01111111 11111111

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

10.220.0.1 through 10.220.127.254

Table F-24 shows the work for this problem, with some explanation of the work following the table. Refer to Chapter 18, "Configuring and Verifying Host Connectivity," for the detailed processes.

Table F-24. Question 8: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart

	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	255	128	0
Address	10	220	100	18
Subnet Number	10	220	0	0
First Address	10	220	0	1
Last Address	10	220	127	254
Broadcast	10	220	127	255

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The third octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 128 = 128 in this case (256 – mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 0 is the multiple of 128 that is closest to 100 but not higher than 100. So, the third octet of the subnet number is 0.

The second part of this process calculates the subnet broadcast address with the tricky part, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 0 + 128 – 1 = 127.

This example tends to confuse people, because a mask with 128 in it gives you subnet numbers that just do not seem to look right. Table F-25 gives you the answers for the first several subnets, just to make sure that you are clear about the subnets when using this mask with a Class A network.

Table F-25. Question 8: First Four Subnets

	Zero Subnet	2nd Subnet	3rd Subnet	4th Subnet
Subnet	10.0.0.0	10.0.128.0	10.1.0.0	10.1.128.0
First Address	10.0.0.1	10.0.128.1	10.1.0.1	10.1.128.1
Last Address	10.0.127.254	10.0.255.254	10.1.127.254	10.1.255.254
Broadcast	10.0.127.255	10.0.255.255	10.1.127.255	10.1.255.255

Answer to Problem 9

Table F-26. Question 9: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts

Item	Example	Rules to Remember
Address	172.31.100.100	—
Mask	255.255.192.0	—
Number of network bits	16	Always defined by Class A, B, C
Number of host bits	14	Always defined as number of binary 0s in mask
Number of subnet bits	2	32 – (network size + host size)
Number of subnets	$2^2 = 4$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^{14} - 2 = 16,382$	$2^{\text{number-of-host-bits}} - 2$

Table F-27 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-27. Question 9: Binary Calculation of Subnet and Broadcast Addresses

Address	172.31.100.100	10101100 00011111 01**100100** **01100100**
Mask	255.255.192.0	11111111 11111111 11**000000** **00000000**
AND result (subnet number)	172.31.64.0	10101100 00011111 01**000000** **00000000**
Change host to 1s (broadcast address)	172.31.127.255	10101100 00011111 01**111111** **11111111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

172.31.64.1 through 172.31.127.254

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-28 shows the work for this problem, with some explanation of the work following the table.

Table F-28. Question 9: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart

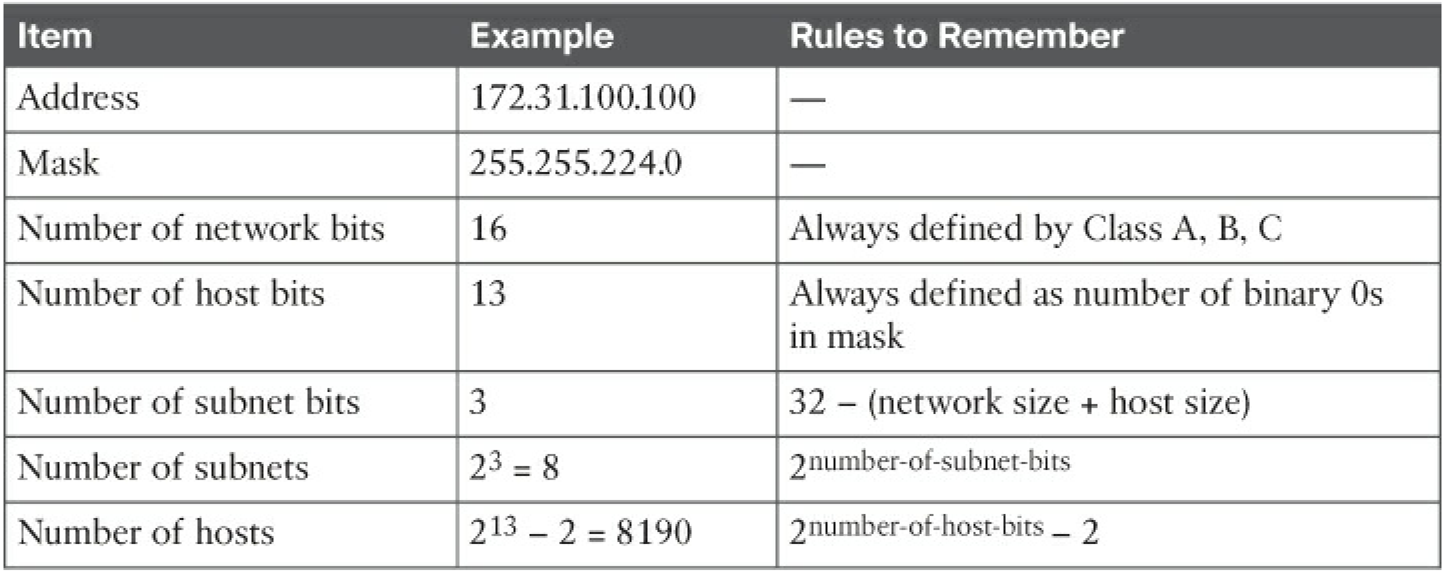
	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	255	192	0
Address	172	31	100	100
Subnet Number	172	31	64	0
First Valid Address	172	31	64	1
Last Valid Address	172	31	127	254
Broadcast	172	31	127	255

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The third octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 192 = 64 in this case (256 – mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 64 is the multiple of 64 that is closest to 100 but not higher than 100. So, the third octet of the subnet number is 64.

The second part of this process calculates the subnet broadcast address with the tricky part, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 64 + 64 – 1 = 127.

Answer to Problem 10

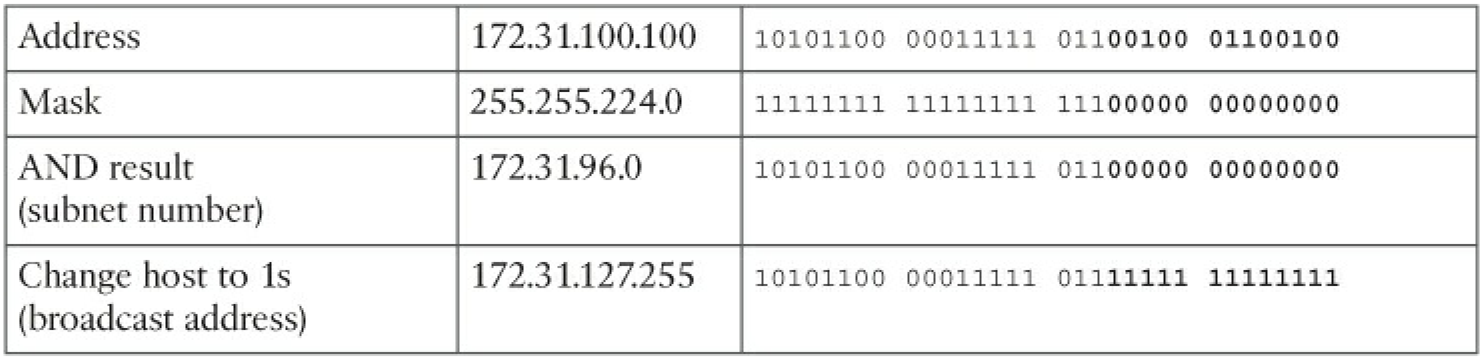
Table F-29. Question 10: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	172.31.100.100	—
Mask	255.255.224.0	—
Number of network bits	16	Always defined by Class A, B, C
Number of host bits	13	Always defined as number of binary 0s in mask
Number of subnet bits	3	32 – (network size + host size)
Number of subnets	$2^3 = 8$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^{13} - 2 = 8190$	$2^{\text{number-of-host-bits}} - 2$

Table F-30 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-30. Question 10: Binary Calculation of Subnet and Broadcast Addresses



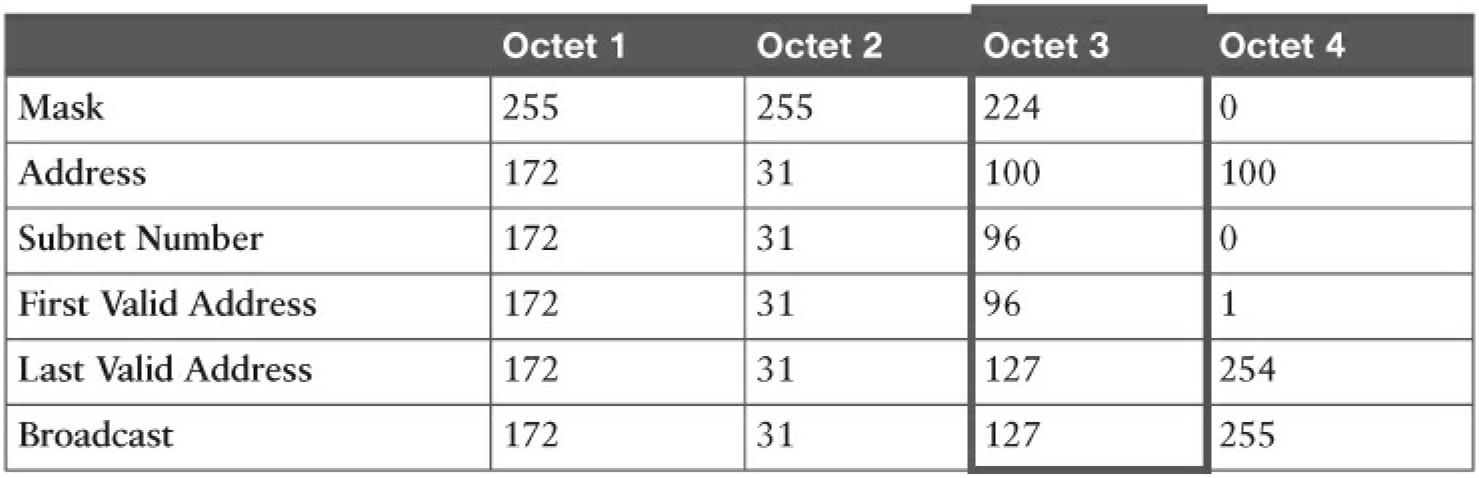
Address	172.31.100.100	10101100 00011111 011**00100** **01100100**
Mask	255.255.224.0	11111111 11111111 111**00000** **00000000**
AND result (subnet number)	172.31.96.0	10101100 00011111 011**00000** **00000000**
Change host to 1s (broadcast address)	172.31.127.255	10101100 00011111 011**11111** **11111111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

172.31.96.1 through 172.31.127.254

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-31 shows the work for this problem, with some explanation of the work following the table.

Table F-31. Question 10: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart



	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	255	224	0
Address	172	31	100	100
Subnet Number	172	31	96	0
First Valid Address	172	31	96	1
Last Valid Address	172	31	127	254
Broadcast	172	31	127	255

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The third octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 − 224 = 32 in this case (256 − mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 96 is the multiple of 32 that is closest to 100 but not higher than 100. So, the third octet of the subnet number is 96.

The second part of this process calculates the subnet broadcast address, with the tricky parts, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 96 + 32 − 1 = 127.

Answer to Problem 11

Table F-32. Question 11: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts

Item	Example	Rules to Remember
Address	172.31.200.10	—
Mask	255.255.240.0	—
Number of network bits	16	Always defined by Class A, B, C
Number of host bits	12	Always defined as number of binary 0s in mask
Number of subnet bits	4	32 – (network size + host size)
Number of subnets	$2^4 = 16$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^{12} - 2 = 4094$	$2^{\text{number-of-host-bits}} - 2$

Table F-33 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-33. Question 11: Binary Calculation of Subnet and Broadcast Addresses

Address	172.31.200.10	10101100 00011111 1100**1000** **00001010**
Mask	255.255.240.0	11111111 11111111 1111**0000** **00000000**
AND result (subnet number)	172.31.192.0	10101100 00011111 1100**0000** **00000000**
Change host to 1s (broadcast address)	172.31.207.255	10101100 00011111 1100**1111** **11111111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

172.31.192.1 through 172.31.207.254

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-34 shows the work for this problem, with some explanation of the work following the table.

Table F-34. Question 11: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart

	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	255	240	0
Address	172	31	200	10
Subnet Number	172	31	192	0
First Valid Address	172	31	192	1
Last Valid Address	172	31	207	254
Broadcast	172	31	207	255

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The third octet is “interesting” in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 240 = 16 in this case (256 – mask’s value in the interesting octet). The subnet number’s value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address’s value in the interesting octet. In this case, 192 is the multiple of 16 that is closest to 200 but not higher than 200. So, the third octet of the subnet number is 192.

The second part of this process calculates the subnet broadcast address with the tricky part, as usual, in the “interesting” octet. Take the subnet number’s value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address’s value in the interesting octet. In this case, it is 192 + 16 – 1 = 207.

Answer to Problem 12

Table F-35. Question 12: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts

Item	Example	Rules to Remember
Address	172.31.200.10	—
Mask	255.255.248.0	—
Number of network bits	16	Always defined by Class A, B, C
Number of host bits	11	Always defined as number of binary 0s in mask
Number of subnet bits	5	32 – (network size + host size)
Number of subnets	$2^5 = 32$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^{11} - 2 = 2046$	$2^{\text{number-of-host-bits}} - 2$

Table F-36 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-36. Question 12: Binary Calculation of Subnet and Broadcast Addresses

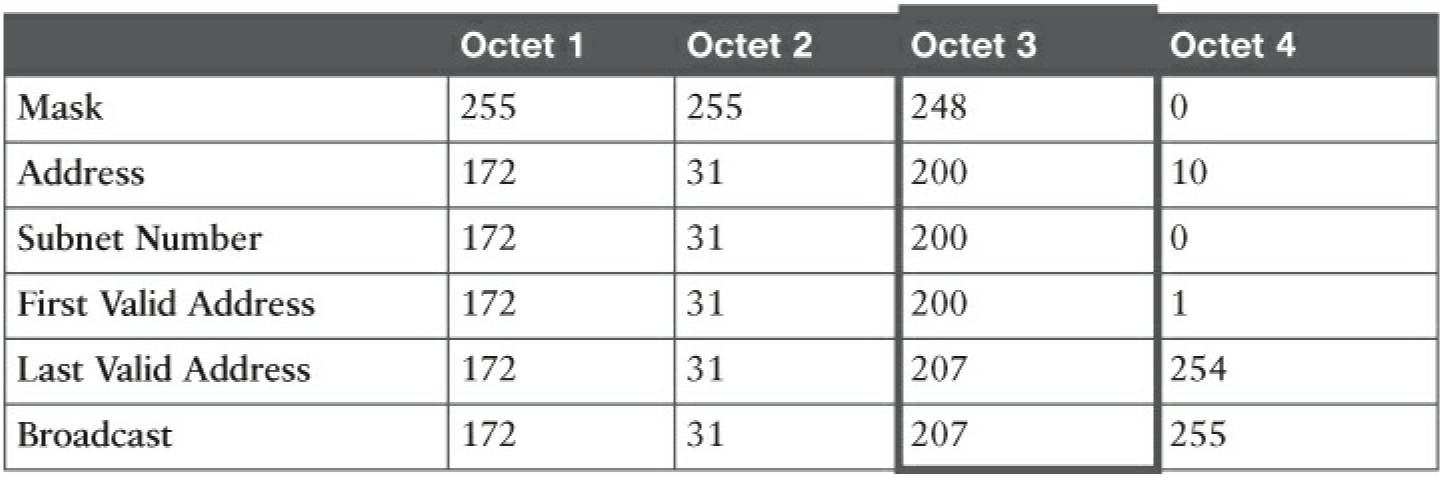
Address	172.31.200.10	10101100 00011111 11001**000** **00001010**
Mask	255.255.248.0	11111111 11111111 11111**000** **00000000**
AND result (subnet number)	172.31.200.0	10101100 00011111 11001**000** **00000000**
Change host to 1s (broadcast address)	172.31.207.255	10101100 00011111 11001**111** **11111111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

172.31.200.1 through 172.31.207.254

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-37 shows the work for this problem, with some explanation of the work following the table.

Table F-37. Question 12: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart



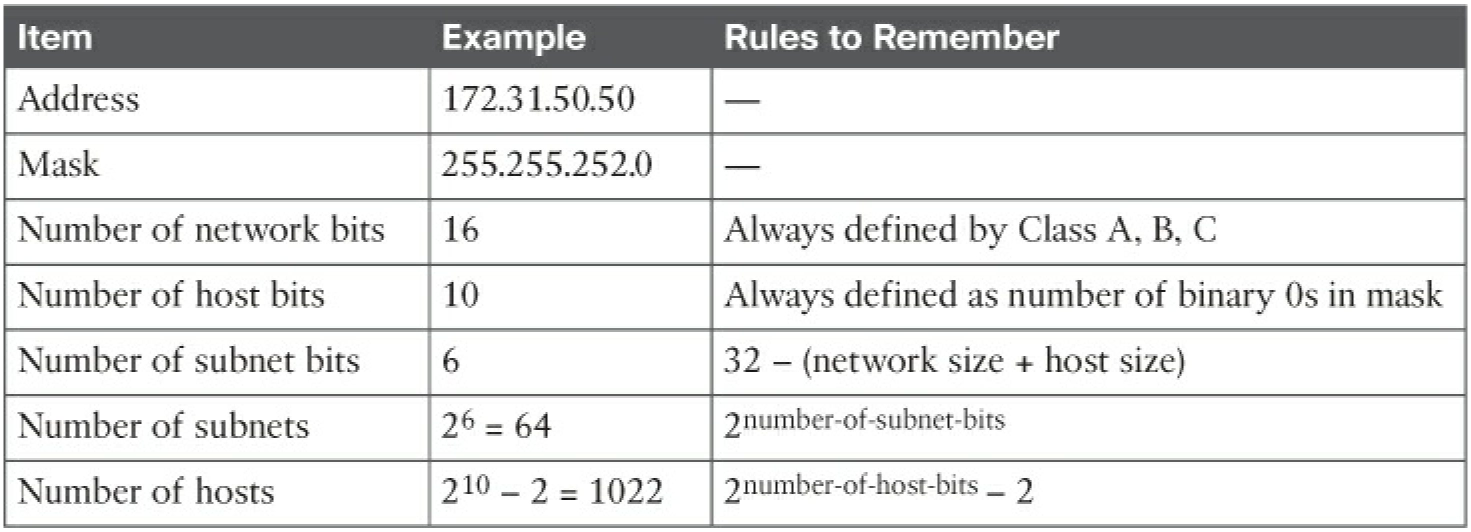
	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	255	248	0
Address	172	31	200	10
Subnet Number	172	31	200	0
First Valid Address	172	31	200	1
Last Valid Address	172	31	207	254
Broadcast	172	31	207	255

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The third octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 248 = 8 in this case (256 – mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 200 is the multiple of 8 that is closest to 200 but not higher than 200. So, the third octet of the subnet number is 200.

The second part of this process calculates the subnet broadcast address, with the tricky part, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 200 + 8 – 1 = 207.

Answer to Problem 13

Table F-38. Question 13: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	172.31.50.50	—
Mask	255.255.252.0	—
Number of network bits	16	Always defined by Class A, B, C
Number of host bits	10	Always defined as number of binary 0s in mask
Number of subnet bits	6	32 – (network size + host size)
Number of subnets	$2^6 = 64$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^{10} - 2 = 1022$	$2^{\text{number-of-host-bits}} - 2$

Table F-39 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-39. Question 13: Binary Calculation of Subnet and Broadcast Addresses

Address	172.31.50.50	10101100 00011111 001100**10** **00110010**
Mask	255.255.252.0	11111111 11111111 111111**00** **00000000**
AND result (subnet number)	172.31.48.0	10101100 00011111 001100**00** **00000000**
Change host to 1s (broadcast address)	172.31.51.255	10101100 00011111 001100**11** **11111111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

172.31.48.1 through 172.31.51.254

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-40 shows the work for this problem, with some explanation of the work following the table.

Table F-40. Question 13: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart

	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	255	252	0
Address	172	31	50	50
Subnet Number	172	31	48	0
First Valid Address	172	31	48	1
Last Valid Address	172	31	51	254
Broadcast	172	31	51	255

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The third octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 252 = 4 in this case (256 – mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 48 is the multiple of 4 that is closest to 50 but not higher than 50. So, the third octet of the subnet number is 48.

The second part of this process calculates the subnet broadcast address, with the tricky part, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 48 + 4 – 1 = 51.

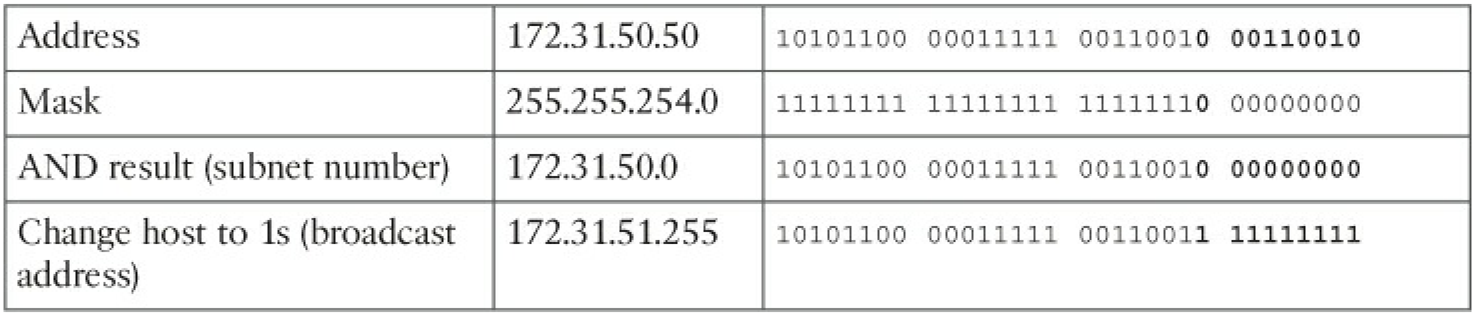
Answer to Problem 14

Table F-41. Question 14: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts

Item	Example	Rules to Remember
Address	172.31.50.50	—
Mask	255.255.254.0	—
Number of network bits	16	Always defined by Class A, B, C
Number of host bits	9	Always defined as number of binary 0s in mask
Number of subnet bits	7	32 – (network size + host size)
Number of subnets	$2^7 = 128$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^9 - 2 = 510$	$2^{\text{number-of-host-bits}} - 2$

Table F-42 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-42. Question 14: Binary Calculation of Subnet and Broadcast Addresses



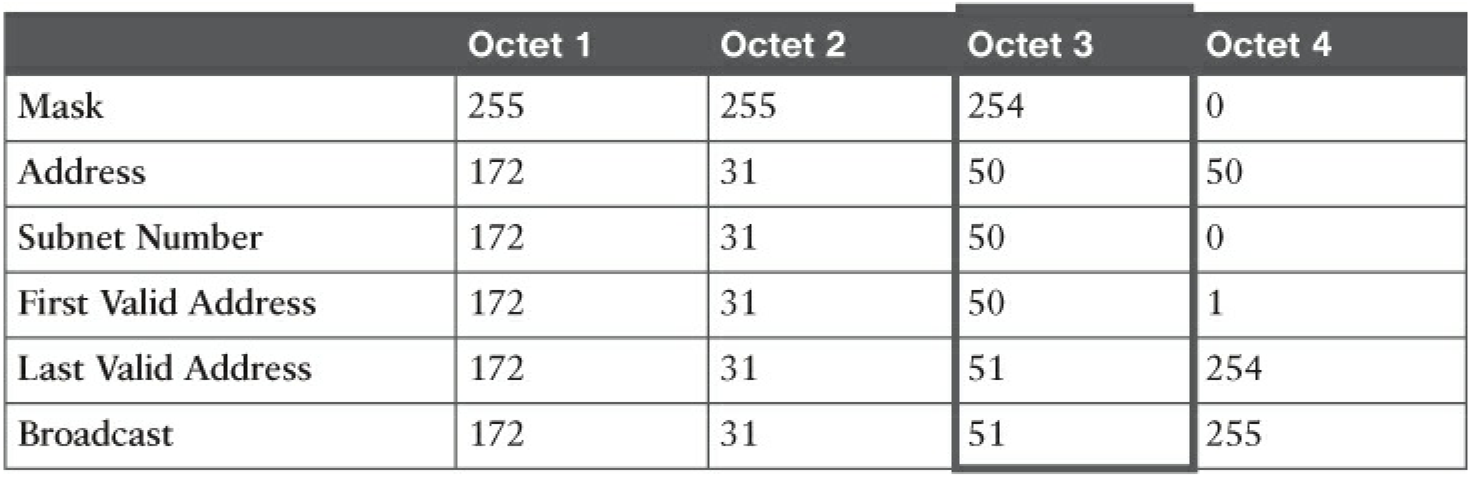
Address	172.31.50.50	10101100 00011111 0011001**0** **00110010**
Mask	255.255.254.0	11111111 11111111 1111111**0** 00000000
AND result (subnet number)	172.31.50.0	10101100 00011111 0011001**0** **00000000**
Change host to 1s (broadcast address)	172.31.51.255	10101100 00011111 0011001**1** **11111111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

172.31.50.1 through 172.31.51.254

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-43 shows the work for this problem, with some explanation of the work following the table.

Table F-43. Question 14: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart



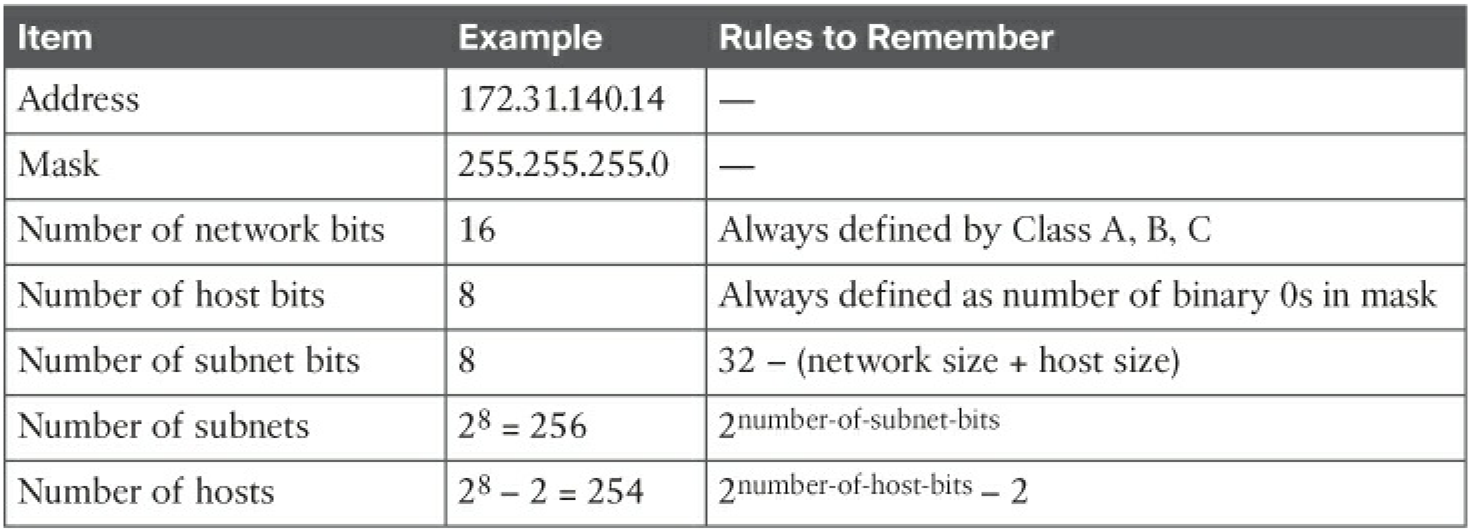
	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	255	254	0
Address	172	31	50	50
Subnet Number	172	31	50	0
First Valid Address	172	31	50	1
Last Valid Address	172	31	51	254
Broadcast	172	31	51	255

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The third octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 254 = 2 in this case (256 – mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 50 is the multiple of 2 that is closest to 50 but not higher than 50. So, the third octet of the subnet number is 50.

The second part of this process calculates the subnet broadcast address with the tricky part, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 50 + 2 – 1 = 51.

Answer to Problem 15

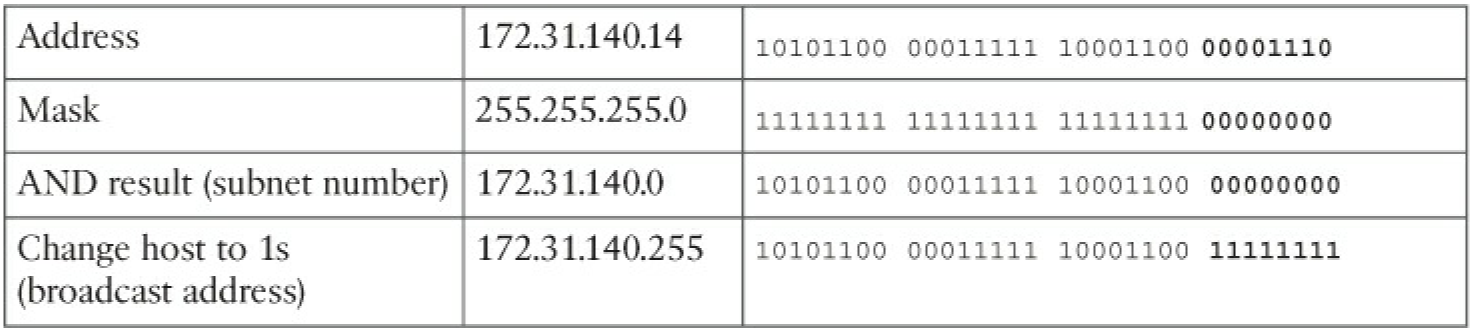
Table F-44. Question 15: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	172.31.140.14	—
Mask	255.255.255.0	—
Number of network bits	16	Always defined by Class A, B, C
Number of host bits	8	Always defined as number of binary 0s in mask
Number of subnet bits	8	32 – (network size + host size)
Number of subnets	$2^8 = 256$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^8 - 2 = 254$	$2^{\text{number-of-host-bits}} - 2$

Table F-45 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-45. Question 15: Binary Calculation of Subnet and Broadcast Addresses



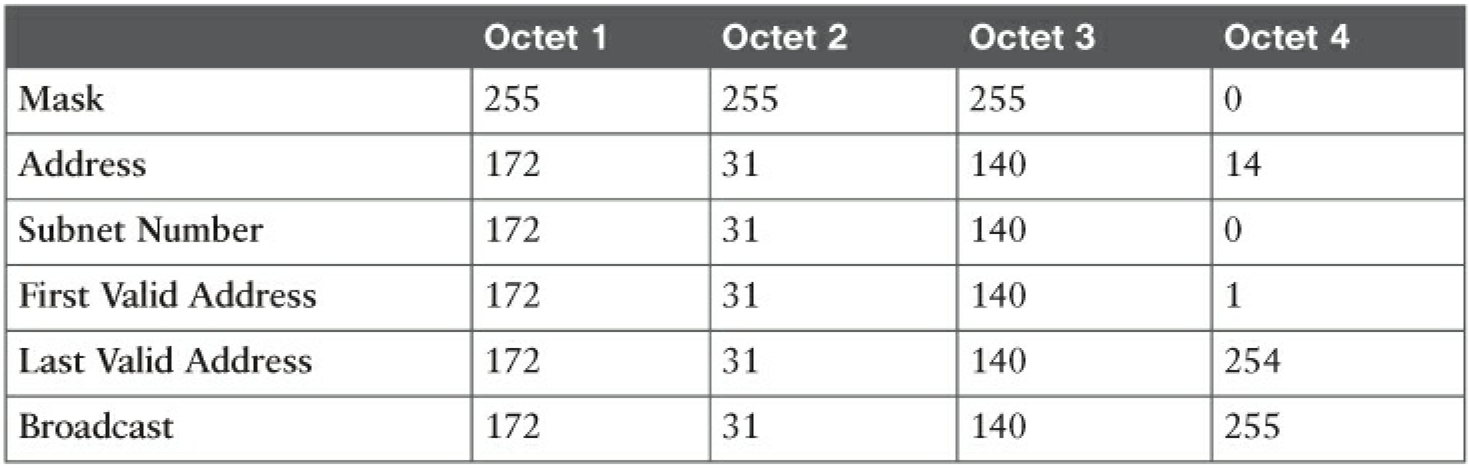
Address	172.31.140.14	10101100 00011111 10001100 **00001110**
Mask	255.255.255.0	11111111 11111111 11111111 **00000000**
AND result (subnet number)	172.31.140.0	10101100 00011111 10001100 **00000000**
Change host to 1s (broadcast address)	172.31.140.255	10101100 00011111 10001100 **11111111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

172.31.140.1 through 172.31.140.254

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-46 shows the work for this problem.

Table F-46. Question 15: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart



	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	255	255	0
Address	172	31	140	14
Subnet Number	172	31	140	0
First Valid Address	172	31	140	1
Last Valid Address	172	31	140	254
Broadcast	172	31	140	255

This subnetting scheme uses an easy mask because all the octets are a 0 or a 255. No math tricks are needed.

Answer to Problem 16

Table F-47. Question 16: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts

Item	Example	Rules to Remember
Address	172.31.140.14	—
Mask	255.255.255.128	—
Number of network bits	16	Always defined by Class A, B, C
Number of host bits	7	Always defined as number of binary 0s in mask
Number of subnet bits	9	32 – (network size + host size)
Number of subnets	$2^9 = 512$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^7 - 2 = 126$	$2^{\text{number-of-host-bits}} - 2$

Table F-48 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-48. Question 16: Binary Calculation of Subnet and Broadcast Addresses

Address	172.31.140.14	10101100 00011111 10001100 0**0001110**
Mask	255.255.255.128	11111111 11111111 11111111 1**0000000**
AND result (subnet number)	172.31.140.0	10101100 00011111 10001100 0**0000000**
Change host to 1s (broadcast address)	172.31.140.127	10101100 00011111 10001100 0**1111111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

172.31.140.1 through 172.31.140.126

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-49 shows the work for this problem, with some explanation of the work following the table.

Table F-49. Question 16: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart

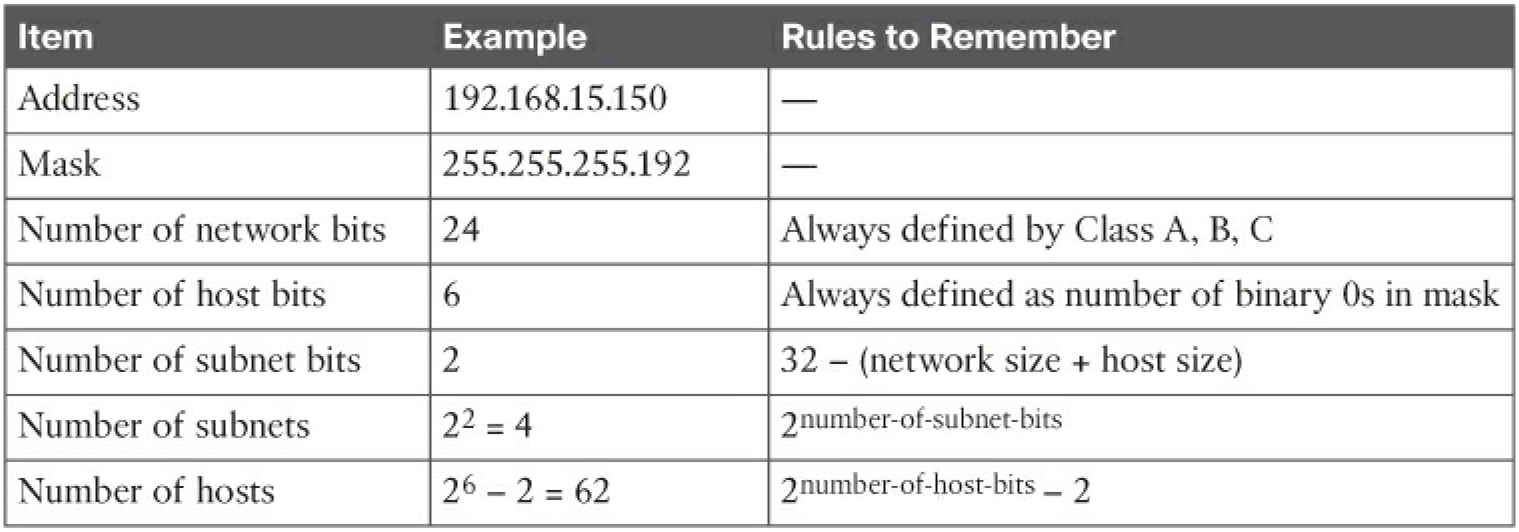
	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	255	255	128
Address	172	31	140	14
Subnet Number	172	31	140	0
First Valid Address	172	31	140	1
Last Valid Address	172	31	140	126
Broadcast	172	31	140	127

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The fourth octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 128 = 128 in this case (256 – mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 0 is the multiple of 128 that is closest to 14 but not higher than 14. So, the fourth octet of the subnet number is 0.

The second part of this process calculates the subnet broadcast address, with the tricky part, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 0 + 128 – 1 = 127.

Answer to Problem 17

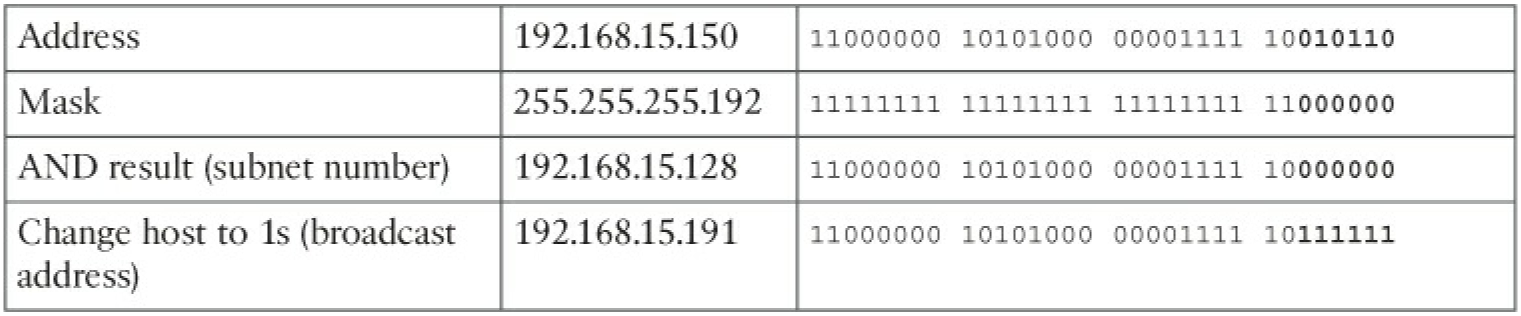
Table F-50. Question 17: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	192.168.15.150	—
Mask	255.255.255.192	—
Number of network bits	24	Always defined by Class A, B, C
Number of host bits	6	Always defined as number of binary 0s in mask
Number of subnet bits	2	32 – (network size + host size)
Number of subnets	$2^2 = 4$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^6 - 2 = 62$	$2^{\text{number-of-host-bits}} - 2$

Table F-51 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-51. Question 17: Binary Calculation of Subnet and Broadcast Addresses



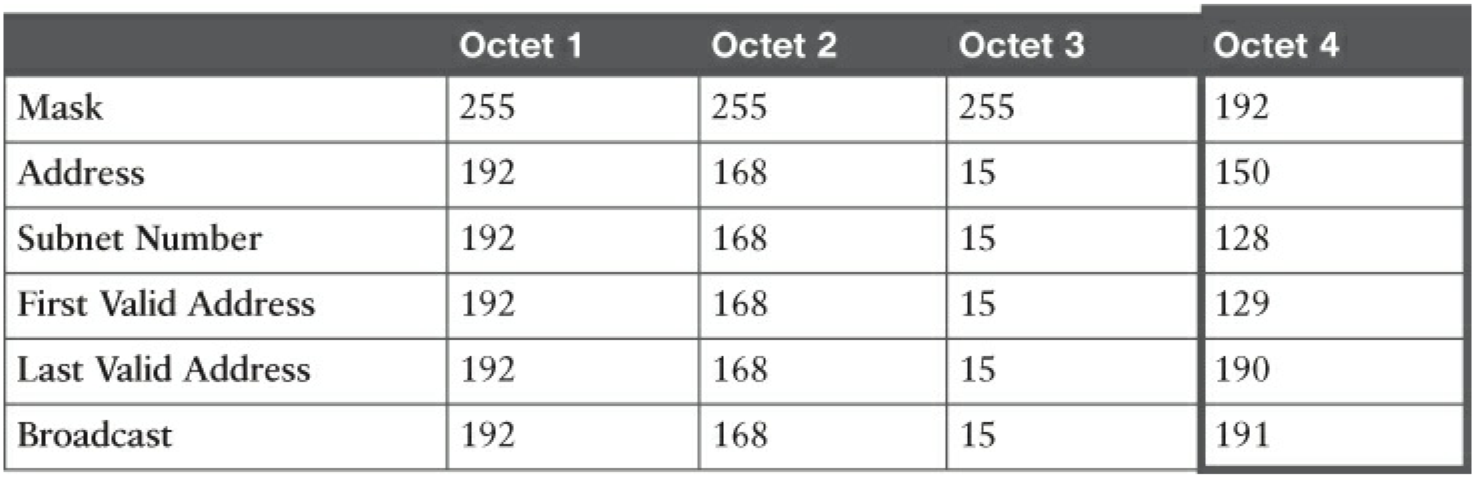
Address	192.168.15.150	11000000 10101000 00001111 10**010110**
Mask	255.255.255.192	11111111 11111111 11111111 11**000000**
AND result (subnet number)	192.168.15.128	11000000 10101000 00001111 10**000000**
Change host to 1s (broadcast address)	192.168.15.191	11000000 10101000 00001111 10**111111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

192.168.15.129 through 192.168.15.190

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-52 shows the work for this problem, with some explanation of the work following the table.

Table F-52. Question 17: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart



	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	255	255	192
Address	192	168	15	150
Subnet Number	192	168	15	128
First Valid Address	192	168	15	129
Last Valid Address	192	168	15	190
Broadcast	192	168	15	191

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The fourth octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 192 = 64 in this case (256 – mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 128 is the multiple of 64 that is closest to 150 but not higher than 150. So, the fourth octet of the subnet number is 128.

The second part of this process calculates the subnet broadcast address, with the tricky part, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 128 + 64 – 1 = 191.

Answer to Problem 18

Table F-53. Question 18: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts

Item	Example	Rules to Remember
Address	192.168.15.150	—
Mask	255.255.255.224	—
Number of network bits	24	Always defined by Class A, B, C
Number of host bits	5	Always defined as number of binary 0s in mask
Number of subnet bits	3	32 – (network size + host size)
Number of subnets	$2^3 = 8$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^5 - 2 = 30$	$2^{\text{number-of-host-bits}} - 2$

Table F-54 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-54. Question 18: Binary Calculation of Subnet and Broadcast Addresses

Address	192.168.15.150	11000000 10101000 00001111 100**10110**
Mask	255.255.255.224	11111111 11111111 11111111 111**00000**
AND result (subnet number)	192.168.15.128	11000000 10101000 00001111 100**00000**
Change host to 1s (broadcast address)	192.168.15.159	11000000 10101000 00001111 100**11111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

192.168.15.129 through 192.168.15.158

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-55 shows the work for this problem, with some explanation of the work following the table.

Table F-55. Question 18: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart

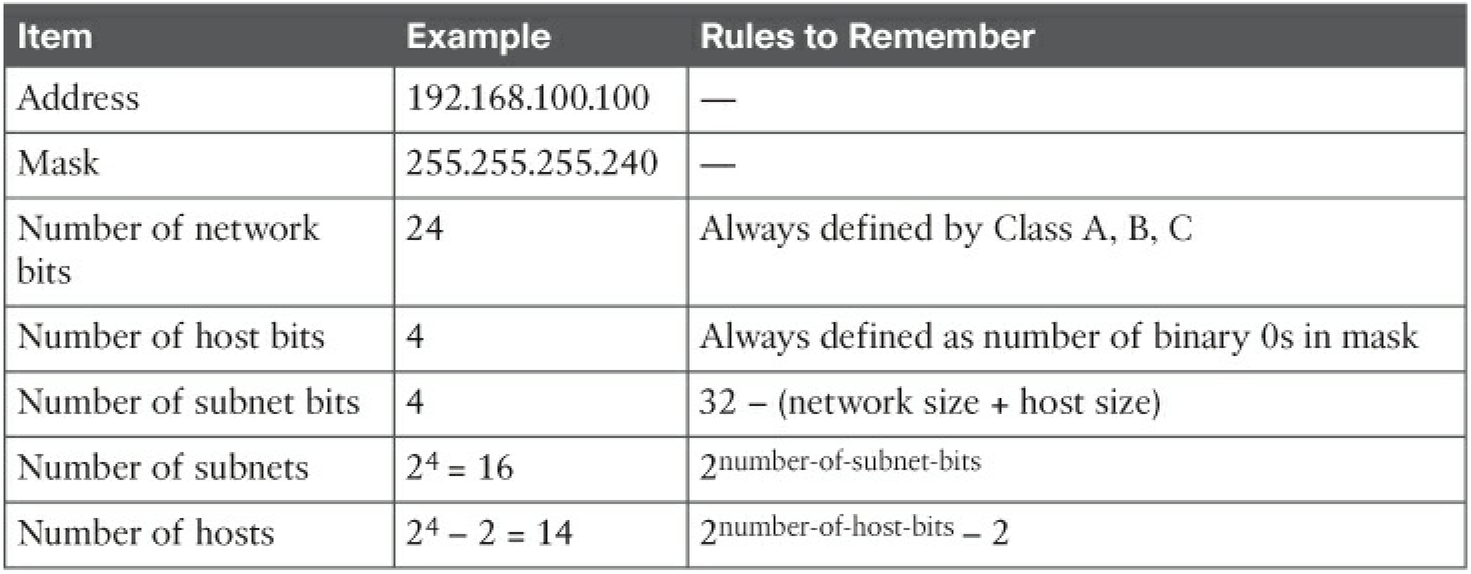
	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	255	255	224
Address	192	168	15	150
Subnet Number	192	168	15	128
First Valid Address	192	168	15	129
Last Valid Address	192	168	15	158
Broadcast	192	168	15	159

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The fourth octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 − 224 = 32 in this case (256 − mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 128 is the multiple of 32 that is closest to 150 but not higher than 150. So, the fourth octet of the subnet number is 128.

The second part of this process calculates the subnet broadcast address, with the tricky part, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 128 + 32 − 1 = 159.

Answer to Problem 19

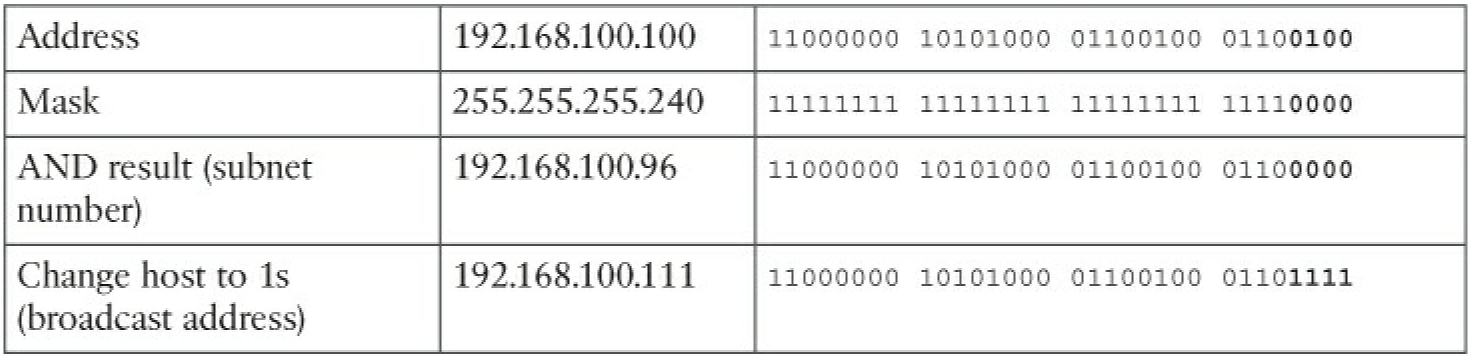
Table F-56. Question 19: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	192.168.100.100	—
Mask	255.255.255.240	—
Number of network bits	24	Always defined by Class A, B, C
Number of host bits	4	Always defined as number of binary 0s in mask
Number of subnet bits	4	32 – (network size + host size)
Number of subnets	$2^4 = 16$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^4 - 2 = 14$	$2^{\text{number-of-host-bits}} - 2$

Table F-57 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-57. Question 19: Binary Calculation of Subnet and Broadcast Addresses



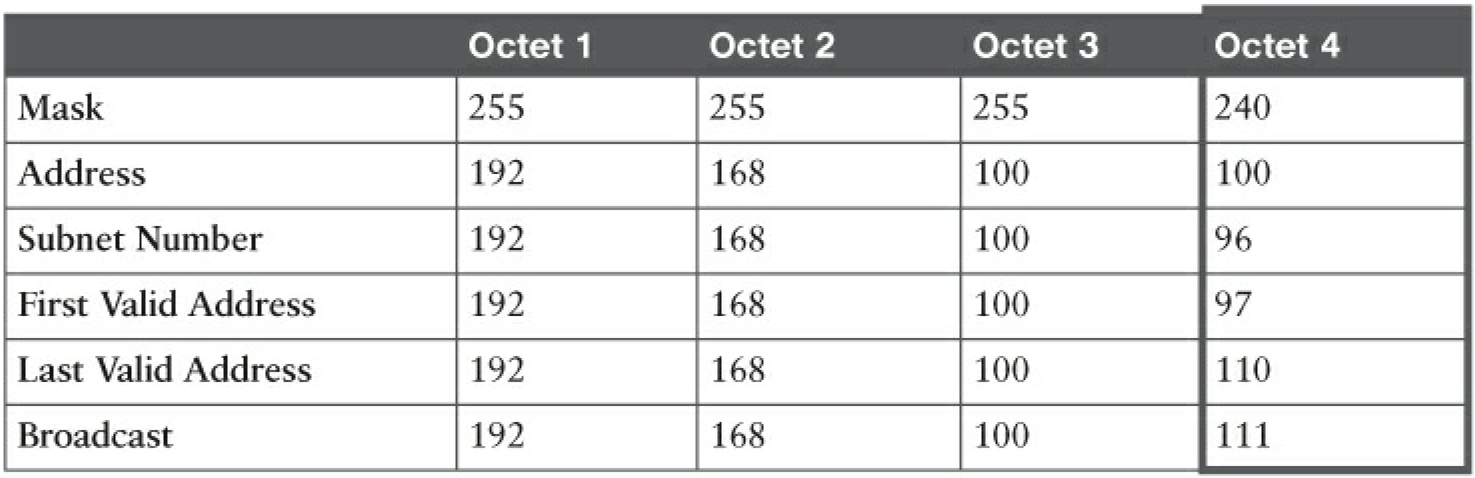
Address	192.168.100.100	11000000 10101000 01100100 0110**0100**
Mask	255.255.255.240	11111111 11111111 11111111 1111**0000**
AND result (subnet number)	192.168.100.96	11000000 10101000 01100100 0110**0000**
Change host to 1s (broadcast address)	192.168.100.111	11000000 10101000 01100100 0110**1111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

192.168.100.97 through 192.168.100.110

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-58 shows the work for this problem, with some explanation of the work following the table.

Table F-58. Question 19: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart



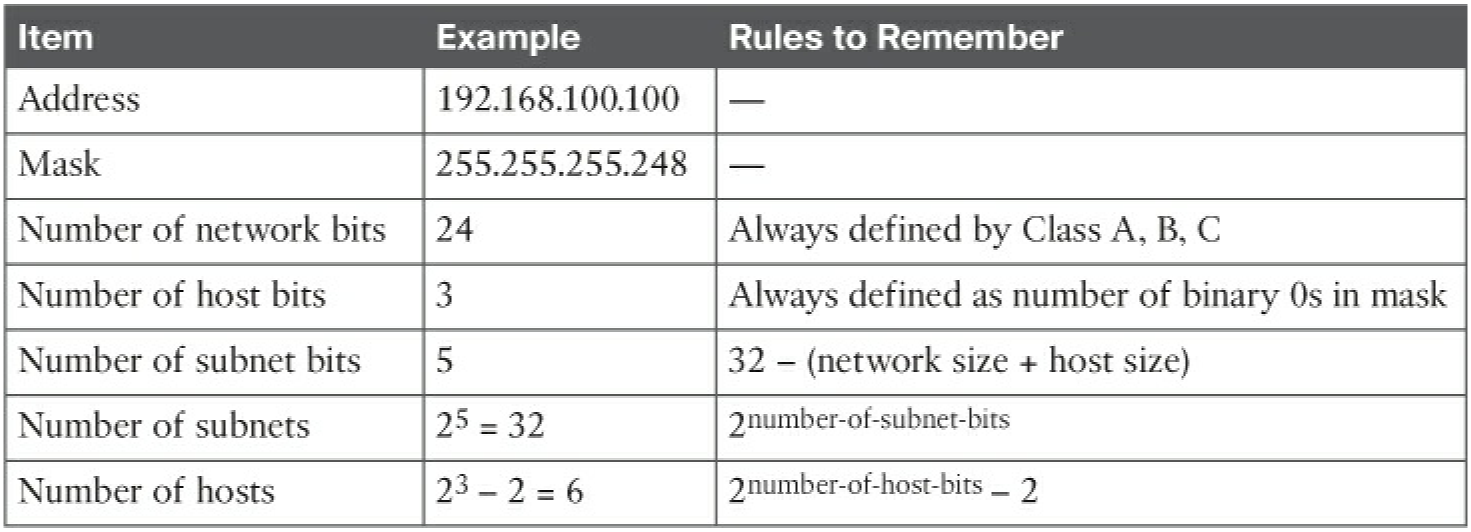
	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	255	255	240
Address	192	168	100	100
Subnet Number	192	168	100	96
First Valid Address	192	168	100	97
Last Valid Address	192	168	100	110
Broadcast	192	168	100	111

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The fourth octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 240 = 16 in this case (256 – mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 96 is the multiple of 16 that is closest to 100 but not higher than 100. So, the fourth octet of the subnet number is 96.

The second part of this process calculates the subnet broadcast address, with the tricky part, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 96 + 16 – 1 = 111.

Answer to Problem 20

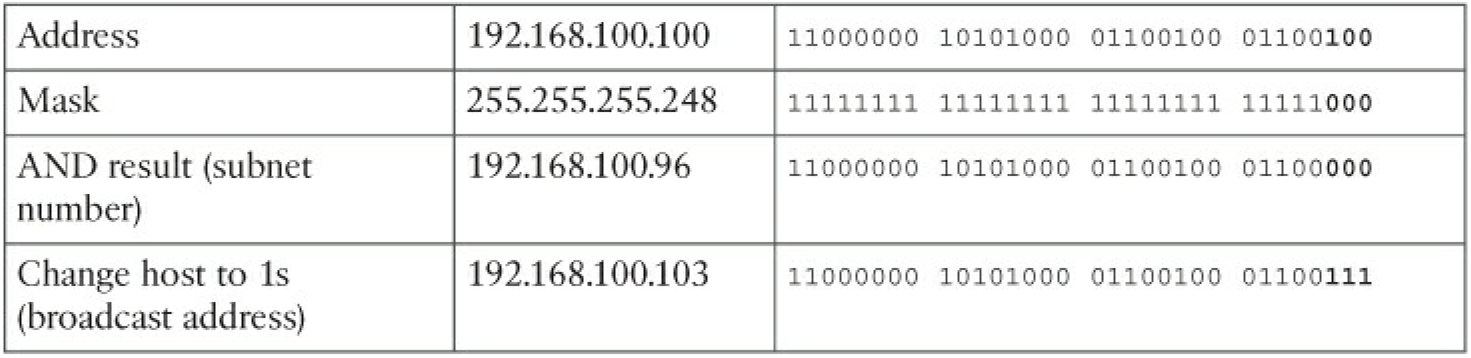
Table F-59. Question 20: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	192.168.100.100	—
Mask	255.255.255.248	—
Number of network bits	24	Always defined by Class A, B, C
Number of host bits	3	Always defined as number of binary 0s in mask
Number of subnet bits	5	32 – (network size + host size)
Number of subnets	$2^5 = 32$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^3 - 2 = 6$	$2^{\text{number-of-host-bits}} - 2$

Table F-60 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-60. Question 20: Binary Calculation of Subnet and Broadcast Addresses



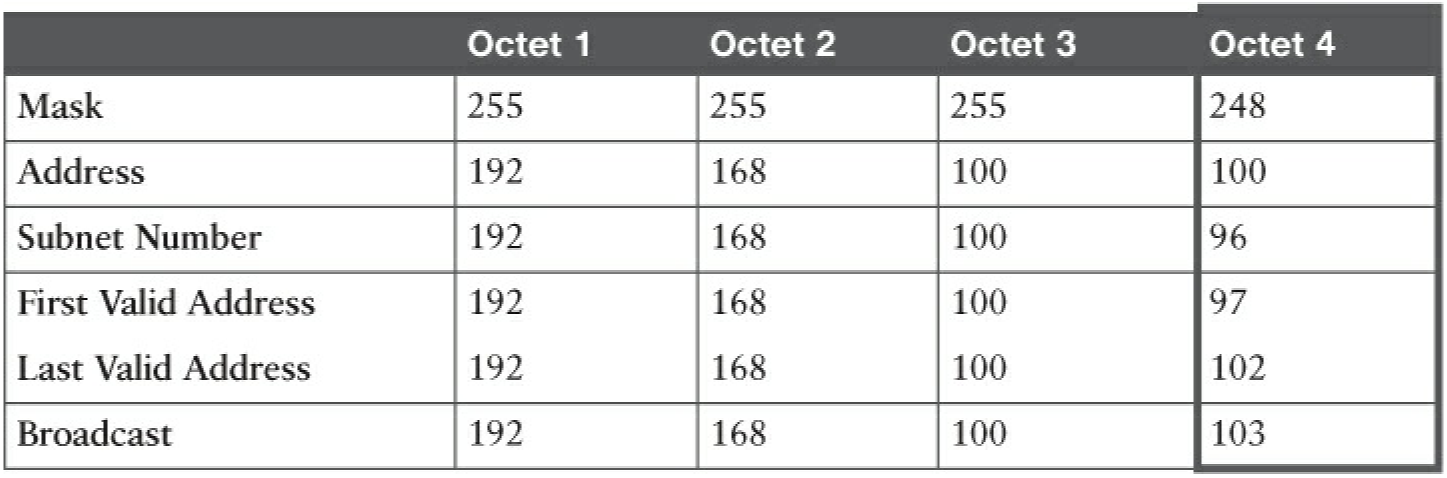
Address	192.168.100.100	11000000 10101000 01100100 01100**100**
Mask	255.255.255.248	11111111 11111111 11111111 11111**000**
AND result (subnet number)	192.168.100.96	11000000 10101000 01100100 01100**000**
Change host to 1s (broadcast address)	192.168.100.103	11000000 10101000 01100100 01100**111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

192.168.100.97 through 192.168.100.102

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-61 shows the work for this problem, with some explanation of the work following the table.

Table F-61. Question 20: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart



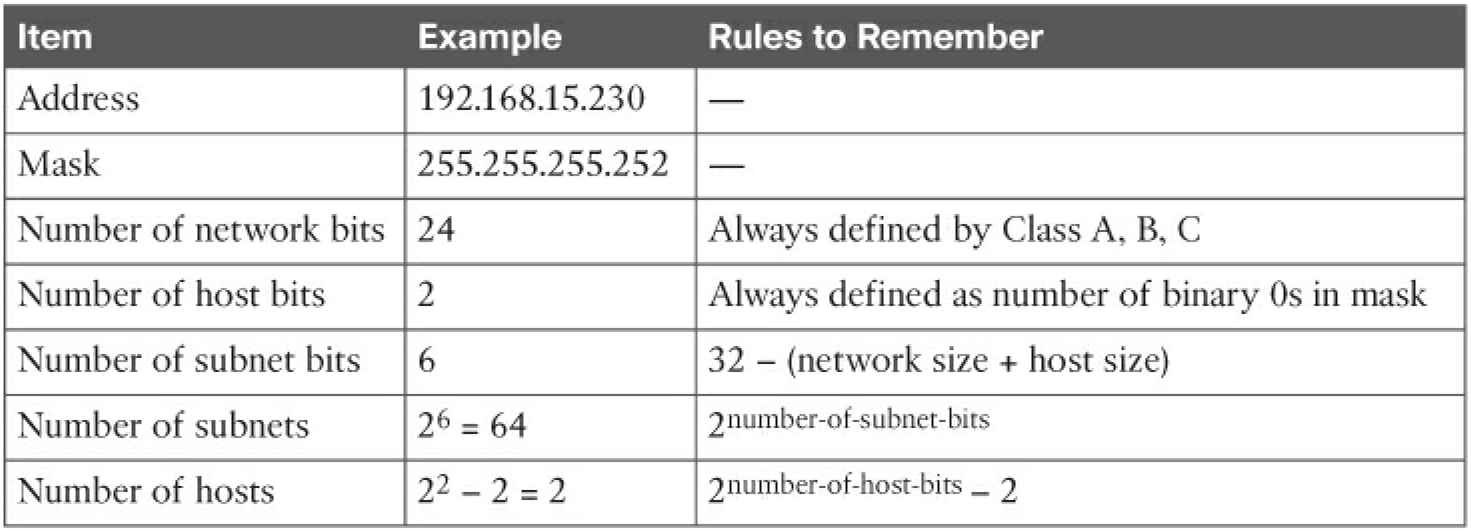
	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	255	255	248
Address	192	168	100	100
Subnet Number	192	168	100	96
First Valid Address	192	168	100	97
Last Valid Address	192	168	100	102
Broadcast	192	168	100	103

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The fourth octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 248 = 8 in this case (256 – mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 96 is the multiple of 8 that is closest to 100 but not higher than 100. So, the fourth octet of the subnet number is 96.

The second part of this process calculates the subnet broadcast address, with the tricky part, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 96 + 8 – 1 = 103.

Answer to Problem 21

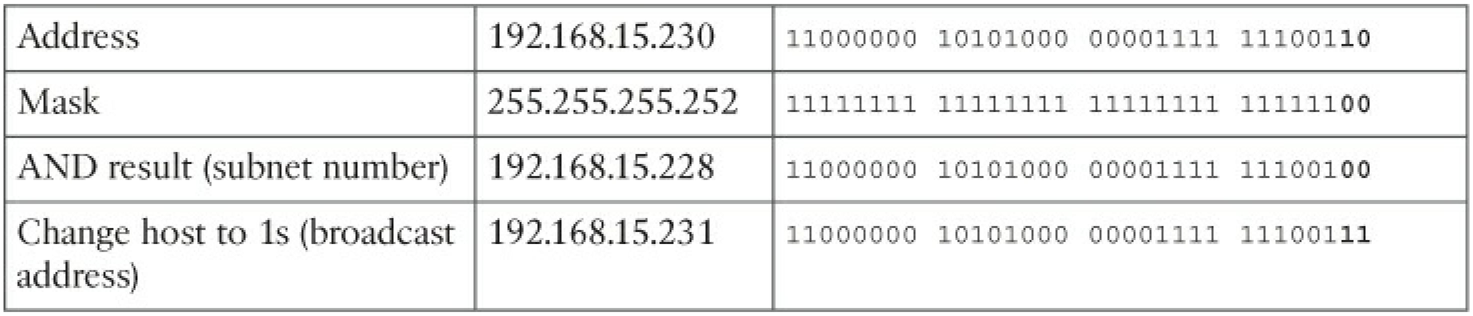
Table F-62. Question 21: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	192.168.15.230	—
Mask	255.255.255.252	—
Number of network bits	24	Always defined by Class A, B, C
Number of host bits	2	Always defined as number of binary 0s in mask
Number of subnet bits	6	32 – (network size + host size)
Number of subnets	$2^6 = 64$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^2 - 2 = 2$	$2^{\text{number-of-host-bits}} - 2$

Table F-63 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-63. Question 21: Binary Calculation of Subnet and Broadcast Addresses



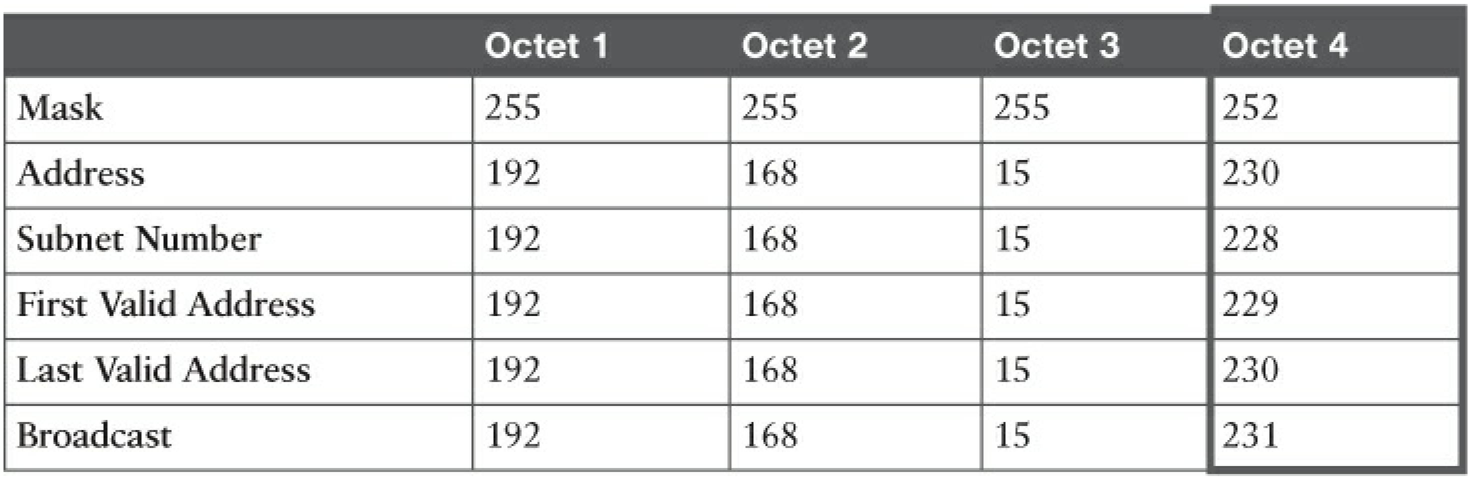
Address	192.168.15.230	11000000 10101000 00001111 111001**10**
Mask	255.255.255.252	11111111 11111111 11111111 111111**00**
AND result (subnet number)	192.168.15.228	11000000 10101000 00001111 111001**00**
Change host to 1s (broadcast address)	192.168.15.231	11000000 10101000 00001111 111001**11**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

192.168.15.229 through 192.168.15.230

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-64 shows the work for this problem, with some explanation of the work following the table.

Table F-64. Question 21: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart



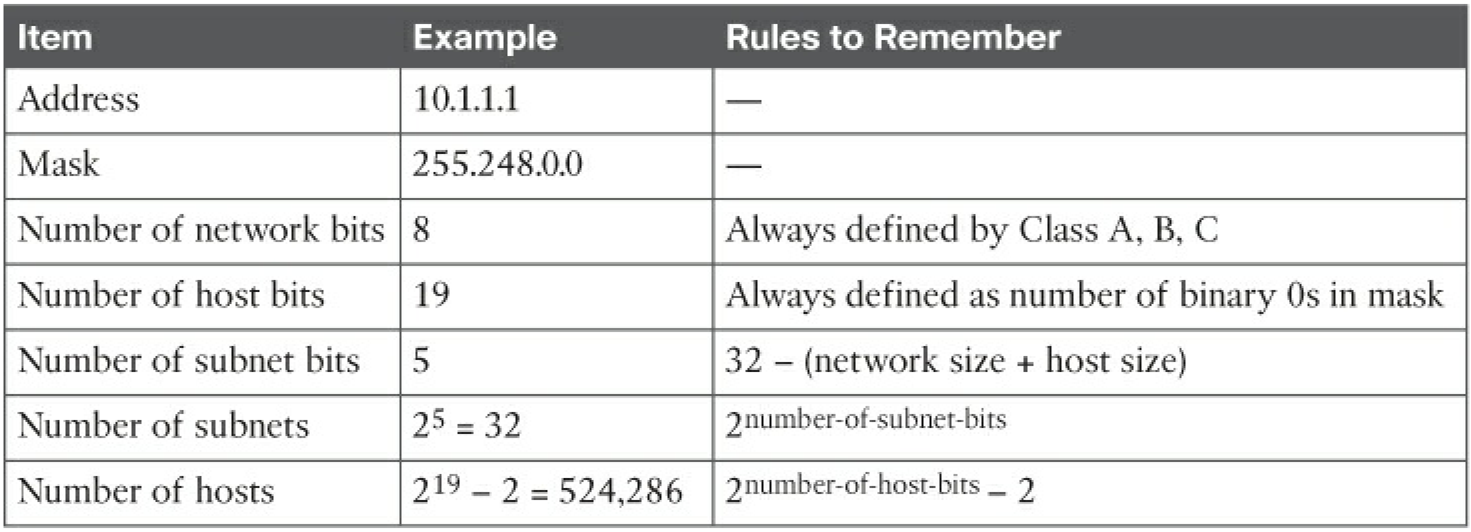
	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	255	255	252
Address	192	168	15	230
Subnet Number	192	168	15	228
First Valid Address	192	168	15	229
Last Valid Address	192	168	15	230
Broadcast	192	168	15	231

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The fourth octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 252 = 4 in this case (256 – mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 228 is the multiple of 4 that is closest to 230 but not higher than 230. So, the fourth octet of the subnet number is 228.

The second part of this process calculates the subnet broadcast address, with the tricky part, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 228 + 4 – 1 = 231.

Answer to Problem 22

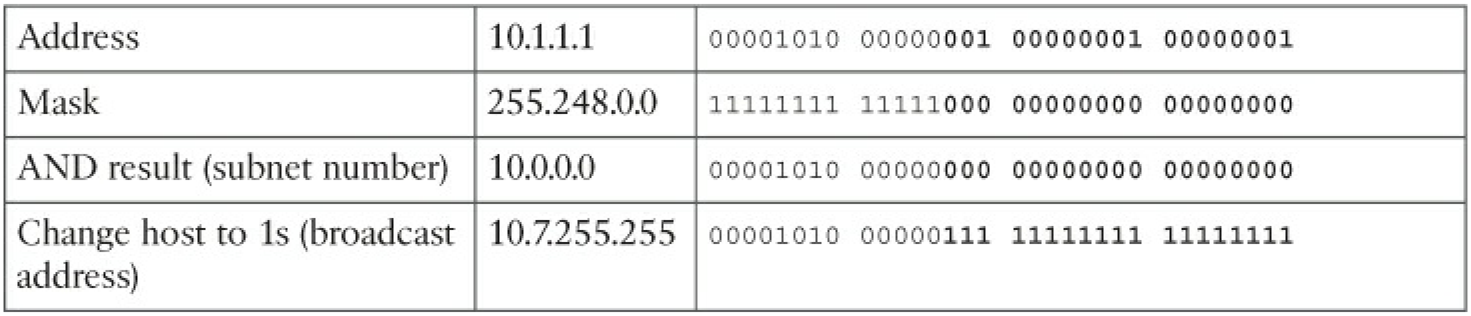
Table F-65. Question 22: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	10.1.1.1	—
Mask	255.248.0.0	—
Number of network bits	8	Always defined by Class A, B, C
Number of host bits	19	Always defined as number of binary 0s in mask
Number of subnet bits	5	32 – (network size + host size)
Number of subnets	$2^5 = 32$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^{19} - 2 = 524,286$	$2^{\text{number-of-host-bits}} - 2$

Table F-66 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-66. Question 22: Binary Calculation of Subnet and Broadcast Addresses



Address	10.1.1.1	00001010 00000**001** **00000001** **00000001**
Mask	255.248.0.0	11111111 11111**000** **00000000** **00000000**
AND result (subnet number)	10.0.0.0	00001010 00000**000** **00000000** **00000000**
Change host to 1s (broadcast address)	10.7.255.255	00001010 00000**111** **11111111** **11111111**

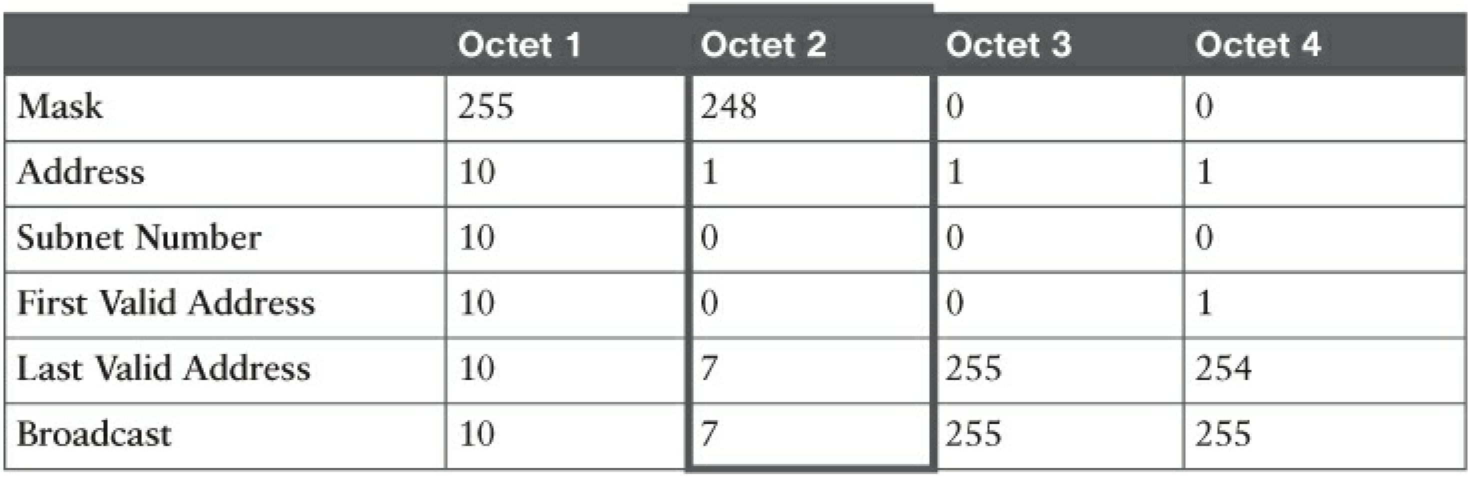
Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

10.0.0.1 through 10.7.255.254

Take a closer look at the subnet part of the subnet address, as shown in bold here: 0000 1010 **0000 0**000 0000 0000 0000 0000. The subnet part of the address is all binary 0s, making this subnet a zero subnet.

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-67 shows the work for this problem, with some explanation of the work following the table.

Table F-67. Question 22: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart



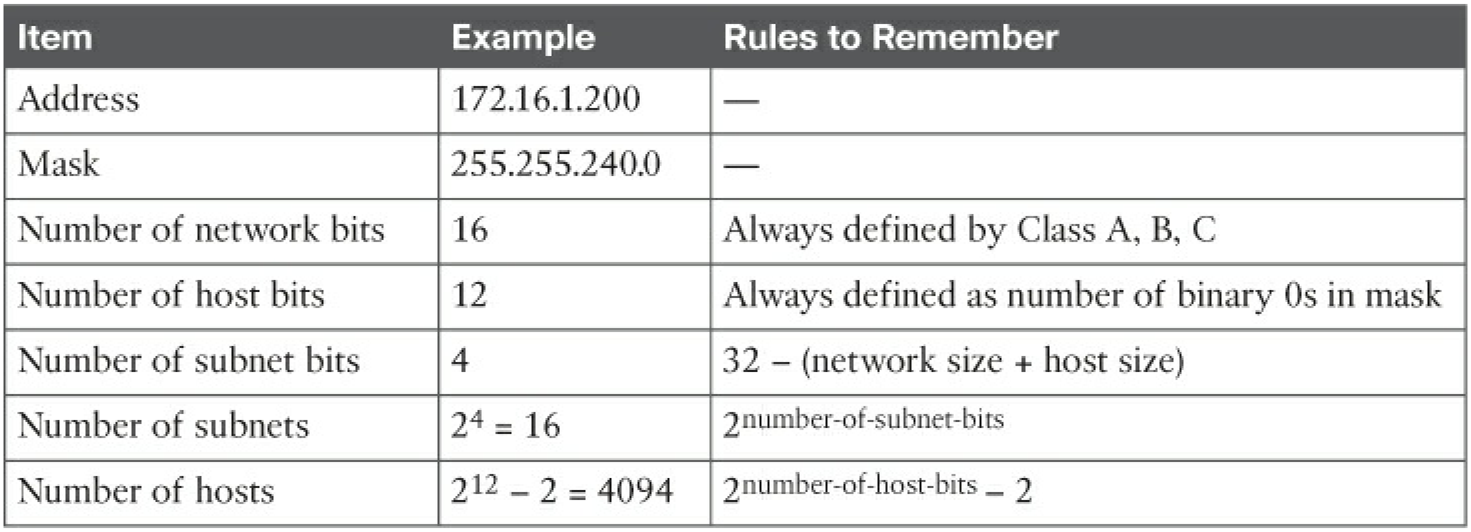
	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	248	0	0
Address	10	1	1	1
Subnet Number	10	0	0	0
First Valid Address	10	0	0	1
Last Valid Address	10	7	255	254
Broadcast	10	7	255	255

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The second octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 248 = 8 in this case (256 – mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 0 is the multiple of 8 that is closest to 1 but not higher than 1. So, the second octet of the subnet number is 0.

The second part of this process calculates the subnet broadcast address, with the tricky part, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 0 + 8 – 1 = 7.

Answer to Problem 23

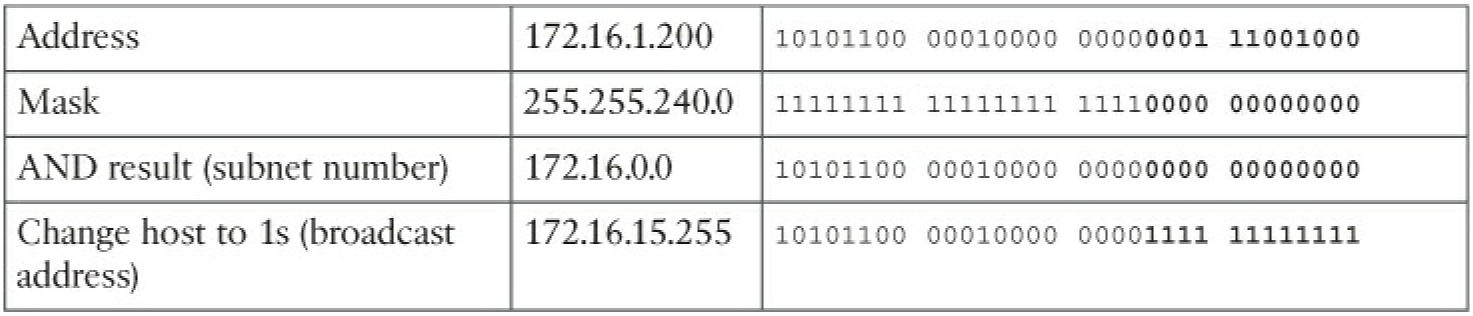
Table F-68. Question 23: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	172.16.1.200	—
Mask	255.255.240.0	—
Number of network bits	16	Always defined by Class A, B, C
Number of host bits	12	Always defined as number of binary 0s in mask
Number of subnet bits	4	32 – (network size + host size)
Number of subnets	$2^4 = 16$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^{12} - 2 = 4094$	$2^{\text{number-of-host-bits}} - 2$

Table F-69 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-69. Question 23: Binary Calculation of Subnet and Broadcast Addresses



Address	172.16.1.200	10101100 00010000 0000**0001** **11001000**
Mask	255.255.240.0	11111111 11111111 1111**0000** **00000000**
AND result (subnet number)	172.16.0.0	10101100 00010000 0000**0000** **00000000**
Change host to 1s (broadcast address)	172.16.15.255	10101100 00010000 0000**1111** **11111111**

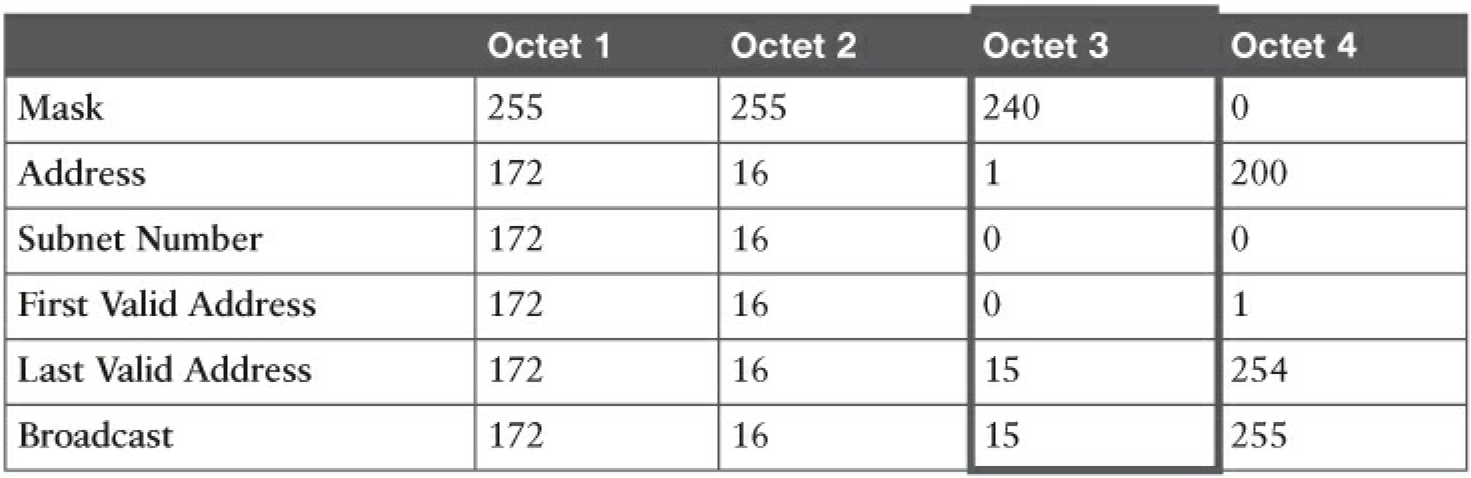
Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

172.16.0.1 through 172.16.15.254

Take a closer look at the subnet part of the subnet address, as shown in bold here: 1010 1100 0001 0000 **0000** 0000 0000 0000. The subnet part of the address is all binary 0s, making this subnet a zero subnet.

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-70 shows the work for this problem, with some explanation of the work following the table.

Table F-70. Question 23: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart



	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	255	240	0
Address	172	16	1	200
Subnet Number	172	16	0	0
First Valid Address	172	16	0	1
Last Valid Address	172	16	15	254
Broadcast	172	16	15	255

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The third octet is "interesting" in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 240 = 16 in this case (256 – mask's value in the interesting octet). The subnet number's value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address's value in the interesting octet. In this case, 0 is the multiple of 16 that is closest to 1 but not higher than 1. So, the third octet of the subnet number is 0.

The second part of this process calculates the subnet broadcast address, with the tricky part, as usual, in the "interesting" octet. Take the subnet number's value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address's value in the interesting octet. In this case, it is 0 + 16 – 1 = 15.

Answer to Problem 24

Table F-71. Question 24: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts

Item	Example	Rules to Remember
Address	172.16.0.200	—
Mask	255.255.255.192	—
Number of network bits	16	Always defined by Class A, B, C
Number of host bits	6	Always defined as number of binary 0s in mask
Number of subnet bits	10	32 – (network size + host size)
Number of subnets	$2^{10} = 1024$	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^6 - 2 = 62$	$2^{\text{number-of-host-bits}} - 2$

Table F-72 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-72. Question 24: Binary Calculation of Subnet and Broadcast Addresses

Address	172.16.0.200	10101100 00010000 00000000 11**001000**
Mask	255.255.255.192	11111111 11111111 11111111 11**000000**
AND result (subnet number)	172.16.0.192	10101100 00010000 00000000 11**000000**
Change host to 1s (broadcast address)	172.16.0.255	10101100 00010000 00000000 11**111111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

172.16.0.193 through 172.16.0.254

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-73 shows the work for this problem, with some explanation of the work following the table.

Table F-73. Question 24: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart

	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	255	255	192
Address	172	16	0	200
Subnet Number	172	16	0	192
First Valid Address	172	16	0	193
Last Valid Address	172	16	0	254
Broadcast	172	16	0	255

This subnetting scheme uses a difficult mask because one of the octets is not a 0 or a 255. The fourth octet is “interesting” in this case. The key part of the trick to get the right answers is to calculate the magic number, which is 256 – 192 = 64 in this case (256 – mask’s value in the interesting octet). The subnet number’s value in the interesting octet (inside the box) is the multiple of the magic number that is not higher than the original IP address’s value in the interesting octet. In this case, 192 is the multiple of 64 that is closest to 200 but not higher than 200. So, the fourth octet of the subnet number is 192.

The second part of this process calculates the subnet broadcast address, with the tricky part, as usual, in the “interesting” octet. Take the subnet number’s value in the interesting octet, add the magic number, and subtract 1. That is the broadcast address’s value in the interesting octet. In this case, it is 192 + 64 – 1 = 255.

You can easily forget that the subnet part of this address, when using this mask, actually covers all the third octet as well as 2 bits of the fourth octet. For example, the valid subnet numbers in order are listed here:

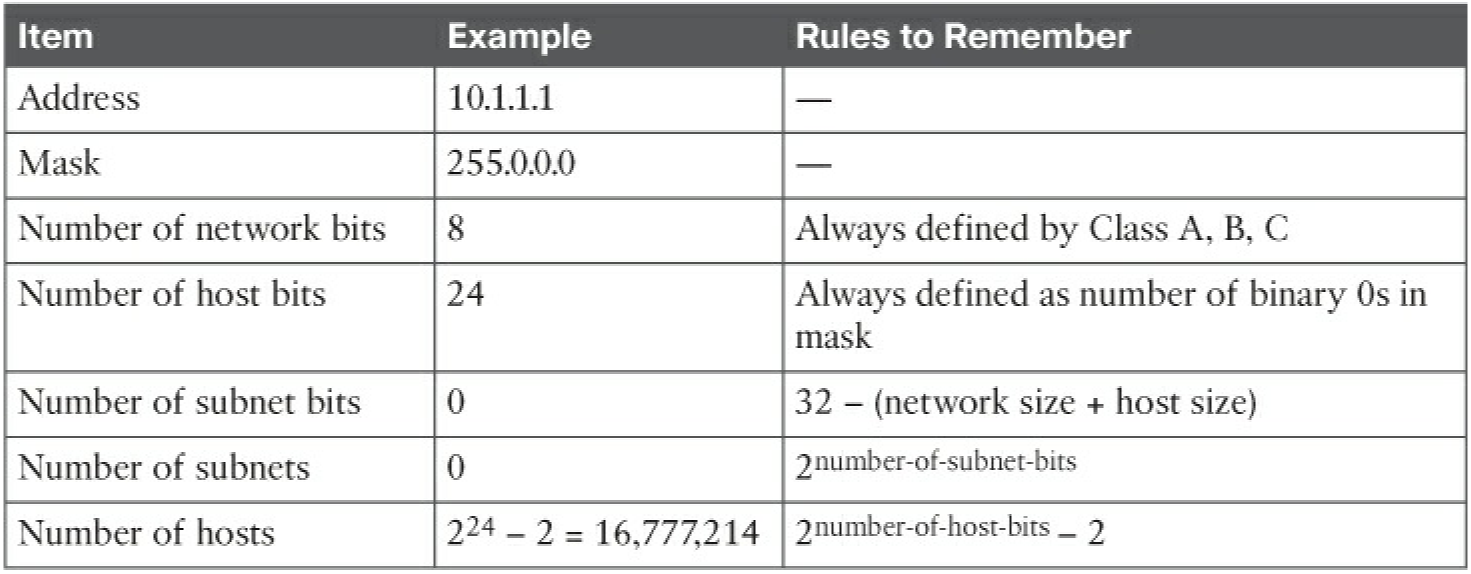
172.16.0.0 (zero subnet)
172.16.0.64
172.16.0.128
172.16.0.192
172.16.1.0
172.16.1.64
172.16.1.128
172.16.1.192
172.16.2.0
172.16.2.64
172.16.2.128
172.16.2.192
172.16.3.0
172.16.3.64
172.16.3.128
172.16.3.192

And so on.

Answer to Problem 25

Congratulations! You made it through the extra practice in this appendix! Here is an easy one to complete your review—one with no subnetting at all.

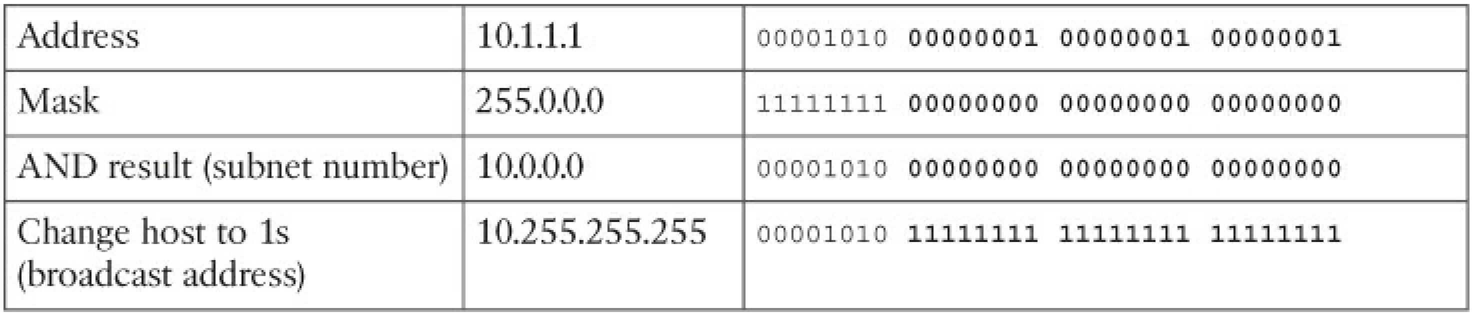
Table F-74. Question 25: Size of Network, Subnet, Host, Number of Subnets, Number of Hosts



Item	Example	Rules to Remember
Address	10.1.1.1	—
Mask	255.0.0.0	—
Number of network bits	8	Always defined by Class A, B, C
Number of host bits	24	Always defined as number of binary 0s in mask
Number of subnet bits	0	32 – (network size + host size)
Number of subnets	0	$2^{\text{number-of-subnet-bits}}$
Number of hosts	$2^{24} - 2 = 16{,}777{,}214$	$2^{\text{number-of-host-bits}} - 2$

Table F-75 contains the important binary calculations for finding the subnet number and subnet broadcast address. To calculate the subnet number, perform a Boolean AND on the address and mask. To find the broadcast address for this subnet, change all the host bits to binary 1s in the subnet number. The host bits are in **bold** print in the table.

Table F-75. Question 25: Binary Calculation of Subnet and Broadcast Addresses



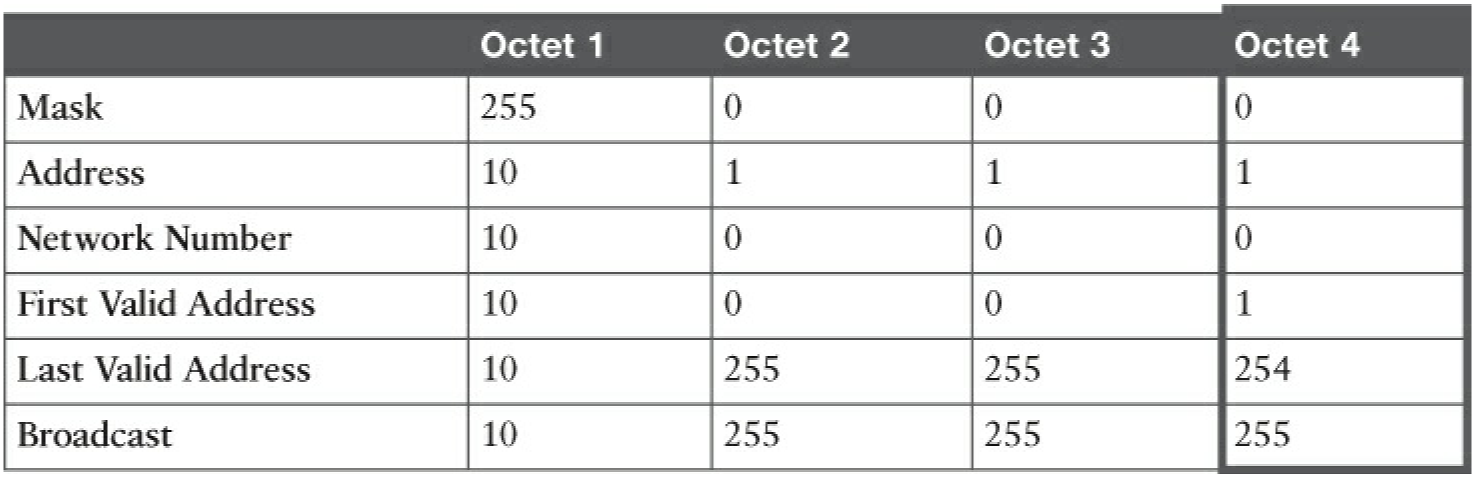
Address	10.1.1.1	00001010 **00000001 00000001 00000001**
Mask	255.0.0.0	11111111 **00000000 00000000 00000000**
AND result (subnet number)	10.0.0.0	00001010 **00000000 00000000 00000000**
Change host to 1s (broadcast address)	10.255.255.255	00001010 **11111111 11111111 11111111**

Just add 1 to the subnet number to get the first valid IP address; just subtract 1 from the broadcast address to get the last valid IP address. In this case:

10.0.0.1 through 10.255.255.254

Alternatively, you can use the processes that only use decimal math to find the subnet and broadcast address. Table F-76 shows the work for this problem.

Table F-76. Question 25: Subnet, Broadcast, and First and Last Addresses Calculated Using the Subnet Chart



	Octet 1	Octet 2	Octet 3	Octet 4
Mask	255	0	0	0
Address	10	1	1	1
Network Number	10	0	0	0
First Valid Address	10	0	0	1
Last Valid Address	10	255	255	254
Broadcast	10	255	255	255

Appendix G. Practice for Chapter 19: Subnet Design

This appendix exists as two halves to match the two major sections of the chapter. The first half lists mask design problems, and then the answers to those problems. The second half lists problems where you need to find the subnet ID, but with less than 8 subnet bits and with more than 8 subnet bits.

To solve these problems, use the processes explained in Chapter 19 of *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*.

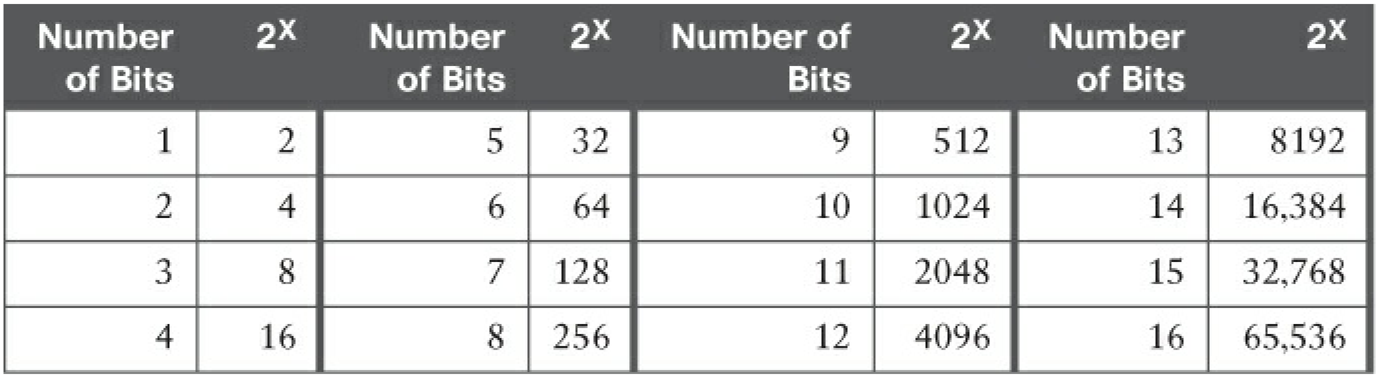
Mask Design Practice Problems

This section lists problems with a short set of requirements regarding how a particular classful network should be subnetted. The requirements include the classful network, the number of subnets the design must support, and the number of hosts in each subnet. For each problem, supply the following information:

- The minimum number of subnet and host bits needed in the mask to support the design requirements ■ The dotted-decimal format mask(s) that meet the requirements ■ The mask you would choose if the problem said to maximize the number of subnets ■ The mask you would choose if the problem said to maximize the number of hosts per subnet Also note that you should assume that the two special subnets in each network—the zero subnet and broadcast subnet—are allowed to be used for these questions.

When doing the problems, the information in Table G-1 can be helpful. Note that Appendix A, "Numeric Reference Tables," in the printed book, also includes this table.

Table G-1. Powers of 2



Number of Bits	2^X	Number of Bits	2^X	Number of Bits	2^X	Number of Bits	2^X
1	2	5	32	9	512	13	8192
2	4	6	64	10	1024	14	16,384
3	8	7	128	11	2048	15	32,768
4	16	8	256	12	4096	16	65,536

Find the key facts for these sets of requirements:

1. Network 10.0.0.0, need 50 subnets, need 200 hosts/subnet
2. Network 172.32.0.0, need 125 subnets, need 125 hosts/subnet
3. Network 192.168.44.0, need 15 subnets, need 6 hosts/subnet
4. Network 10.0.0.0, need 300 subnets, need 500 hosts/subnet
5. Network 172.32.0.0, need 500 subnets, need 15 hosts/subnet
6. Network 172.16.0.0, need 2000 subnets, need 2 hosts/subnet

Mask Design Answers

This section includes the answers to the six problems listed in this appendix. The answer section for each problem explains how to use the process outlined in Chapter 19, "Subnet Design," to find the answers.

Answer to Mask Design Problem 1

Problem 1 shows a Class A network, with 8 network bits, with a minimum of 6 subnet bits and 8 host bits to meet the required number of subnets and hosts/subnet. The following masks all meet the requirements in this problem, with the masks that maximize the number of hosts/subnet and the number of subnets noted:

- 255.252.0.0 (maximizes the number of hosts per subnet) ■ 255.254.0.0
- 255.255.0.0
- 255.255.128.0
- 255.255.192.0
- 255.255.224.0
- 255.255.240.0
- 255.255.248.0
- 255.255.252.0
- 255.255.254.0
- 255.255.255.0 (maximizes the number of subnets) As for the process to find the answers, the following list explains the

details:

> **Note**
>
> The following explanation uses step numbers that match the process listed in Chapter 19 of *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*, but only the steps from that process that apply to this problem. As a result, the step numbers in the explanation are not sequential.

Step 1. The question lists Class A network 10.0.0.0, so there are 8 network bits.

Step 2. The question states that 50 subnets are needed. A mask with 5 subnet bits supplies only 2^5 (32) subnets, but a mask with 6 subnet bits supplies 2^6 (64) subnets. So, the mask needs at least 6 subnet bits.

Step 3. The question states that 200 hosts are needed per subnet. A mask with 7 host bits supplies only 2^7 – 2 (126) hosts per subnet, but a mask with 8 host bits supplies 2^8 – 2 (254) hosts per subnet. So, the mask needs at least 8 host bits.

Step 6A. With N=8, a minimum S=6, and a minimum H=8, multiple masks exist. The first mask, with the minimum number of subnet bits, is *14, found by adding N (8) to the minimum value of S (6). This mask maximizes the number of host bits and therefore maximizes the number of hosts*subnet.

Step 6B. The minimum value of H, the number of host bits, is 8. So, the mask with the fewest H bits, maximizing the number of subnets, is 32 – H = 32 – 8 = /24.

Step 6C. All masks between /14 and /24 also meet the requirements.

Answer to Mask Design Problem 2

Problem 2 shows a Class B network, with 16 network bits, with a minimum of 7 subnet bits and 7 host bits to meet the required number of subnets and hosts/subnet. The following masks all meet the requirements in this problem, with the masks that maximize the number of hosts/subnet and the number of subnets noted:

- 255.255.254.0 (maximizes the number of hosts/subnet) ■ 255.255.255.0
- 255.255.255.128 (maximizes the number of subnets) As for the process to find the answers, the following list explains the details:

Step 1. The question lists Class B network 172.32.0.0, so there are 16 network bits.

Step 2. The question states that 125 subnets are needed. A mask with 6 subnet bits supplies only 2^6 (64) subnets, but a mask with 7 subnet bits supplies 2^7 (128) subnets. So, the mask needs at least 7 subnet bits.

Step 3. The question states that 125 hosts are needed per subnet. A mask with 6 host bits supplies only 2^6 – 2 (62) hosts per subnet, but a mask with 7 host bits supplies 2^7 – 2 (126) hosts per subnet. So, the mask needs at least 7 host bits.

Step 6A. With N=16, a minimum S=7, and a minimum H=7, multiple masks exist. The first mask, with the minimum number of subnet bits, is *23, found by adding N (16) to the minimum value of S (7). This mask maximizes the number of host bits and therefore maximizes the number of hosts*subnet.

Step 6B. The minimum value of H, the number of host bits, is 7. So, the mask with the fewest H bits, maximizing the number of subnets, is 32 – H = 32 – 7 = /25.

Step 6C. All masks between /23 and *25 also meet the requirements* (23, *24, and* 25).

Answer to Mask Design Problem 3

Problem 3 shows a Class C network, with 24 network bits, with a minimum of 4 subnet bits and 3 host bits to meet the required number of subnets and hosts/subnet. The following masks all meet the requirements in this problem, with the masks that maximize the number of hosts/subnet and the number of subnets noted:

- 255.255.255.240 (maximizes the number of hosts/subnet) ■ 255.255.255.248 (maximizes the number of subnets) As for the process to find the answers, the following list explains the details:

Step 1. The question lists Class C network 192.168.44.0, so there are 24 network bits.

Step 2. The question states that 15 subnets are needed. A mask with 3 subnet bits supplies only 2^3 (8) subnets, but a mask with 4 subnet bits supplies 2^4 (16) subnets. So, the mask needs at least 4 subnet bits.

Step 3. The question states that 6 hosts are needed per subnet. A mask with 2 host bits supplies only 2^2 – 2 (2) hosts per subnet, but a mask with 3 host bits supplies 2^3 – 2 (6) hosts per subnet. So, the mask needs at least 3 host bits.

Step 6A. With N=24, a minimum S=4, and a minimum H=3, multiple masks exist. The first mask, with the minimum number of subnet bits, is *28, found by adding N (24) to the minimum value of S (4). This mask maximizes the number of host bits and therefore maximizes the number of hosts*subnet.

Step 6B. The minimum value of H, the number of host bits, is 3. So, the mask with the fewest H bits, maximizing the number of subnets, is 32 – H = 32 – 3 = /29.

Step 6C. Only masks /28 and /29 meet the requirements.

Answer to Mask Design Problem 4

Problem 4 shows a Class A network, with 8 network bits, with a minimum of 9 subnet bits and 9 host bits to meet the required number of subnets and hosts/subnet. The following masks all meet the requirements in this problem, with the masks that maximize the number of hosts/subnet and the number of subnets noted:

- 255.255.128.0 (maximizes the number of hosts/subnet) ■ 255.255.192.0
- 255.255.224.0
- 255.255.240.0
- 255.255.248.0
- 255.255.252.0
- 255.255.254.0 (maximizes the number of subnets) As for the process to find the answers, the following list explains the details:

Step 1. The question lists Class A network 10.0.0.0, so there are 8 network bits.

Step 2. The question states that 300 subnets are needed. A mask with 8 subnet bits supplies only 2^8 (256) subnets, but a mask with 9 subnet bits supplies 2^9 (512) subnets. So, the mask needs at least 9 subnet bits.

Step 3. The question states that 500 hosts are needed per subnet. A mask with 8 host bits supplies only $2^8 - 2$ (254) hosts per subnet, but a mask with 9 host bits supplies $2^9 - 2$ (510) hosts per subnet. So, the mask needs at least 9 host bits.

Step 6A. With N=8, a minimum S=9, and a minimum H=9, multiple masks exist. The first mask, with the minimum number of subnet bits, is *17, found by adding N (8) to the minimum value of S (9). This mask maximizes the number of host bits and therefore maximizes the number of hosts*subnet.

Step 6B. The minimum value of H, the number of host bits, is 9. So, the mask with the fewest H bits, maximizing the number of subnets, is 32 – H = 32 – 9 = /23.

Step 6C. All masks between /17 and *23 also meet the requirements (*17, *18,* 19, *20,* 21, *22,* 23).

Answer to Mask Design Problem 5

Problem 5 shows a Class B network, with 16 network bits, with a minimum of 9 subnet bits and 5 host bits to meet the required number of subnets and hosts/subnet. The following masks all meet the requirements in this problem, with the masks that maximize the number of hosts/subnet and the number of subnets noted:

- 255.255.255.128 (maximizes the number of hosts/subnet) ■ 255.255.255.192
- 255.255.255.224 (maximizes the number of subnets) As for the process to find the answers, the following list explains the details:

Step 1. The question lists Class B network 172.32.0.0, so there are 16 network bits.

Step 2. The question states that 500 subnets are needed. A mask with 8 subnet bits supplies only 2^8 (256) subnets, but a mask with 9 subnet bits supplies 2^9 (512) subnets. So, the mask needs at least 9 subnet bits.

Step 3. The question states that 15 hosts are needed per subnet. A mask with 4 host bits supplies only $2^4 - 2$ (14) hosts per subnet, but a mask with 5 host bits supplies $2^5 - 2$ (30) hosts per subnet. So, the mask needs at least 5 host bits.

Step 6A. With N=16, a minimum S=9, and a minimum H=5, multiple masks exist. The first mask, with the minimum number of subnet bits, is *25, found by adding N (16) to the minimum value of S (9). This mask maximizes the number of host bits and therefore maximizes the number of hosts*subnet.

Step 6B. The minimum value of H, the number of host bits, is 5. So, the mask with the fewest H bits, maximizing the number of subnets, is 32 – H = 32 – 5 = /27.

Step 6C. All masks between /25 and *27 also meet the requirements (*25, *26,* 27).

Answer to Mask Design Problem 6

Problem 6 shows a Class B network, with 16 network bits, with a minimum of 11 subnet bits and 2 host bits to meet the required number of subnets and hosts/subnet. The following masks all meet the requirements in this problem, with the masks that maximize the number of hosts/subnet and the number of subnets noted:

- 255.255.255.224 (maximizes the number of hosts/subnet) ■ 255.255.255.240
- 255.255.255.248
- 255.255.255.252 (maximizes the number of subnets) As for the process to find the answers, the following list explains the details:

Step 1. The question lists Class B network 172.16.0.0, so there are 16 network bits.

Step 2. The question states that 2000 subnets are needed. A mask with 10 subnet bits supplies only 2^{10} (1024) subnets, but a mask with 11 subnet bits supplies 2^{11} (2048) subnets. So, the mask needs at least 11 subnet bits.

Step 3. The question states that 2 hosts are needed per subnet. A mask with 2 host bits supplies $2^2 - 2$ (2) hosts per subnet. So, the mask needs at least 2 host bits.

Step 6A. With N=16, a minimum S=11, and a minimum H=2, multiple masks exist. The first mask, with the minimum number of subnet bits, is *27, found by adding N (16) to the minimum value of S (11). This mask maximizes the number of host bits and therefore maximizes the number of hosts*subnet.

Step 6B. The minimum value of H, the number of host bits, is 2. So, the mask with the fewest H bits, maximizing the number of subnets, is 32 – H = 32 – 2 = /30.

Step 6C. All masks between /27 and *30 also meet the requirements (*27, *28,* 29, /30).

Practice Finding All Subnet IDs

The remainder of this appendix lists two sets of problems. Both problem sets list an IP network and mask; your job is to list all the subnet IDs for each network/mask combination. The first problem set includes problems that happen to have 8 or fewer subnet bits, and the second problem set includes problems that happen to have more than 8 subnet bits. In particular, for each problem, find the following:

- All subnet numbers
- The subnet that is the zero subnet ■ The subnet that is the broadcast subnet To find this information, you can use the processes explained in Chapter 19 of the ICND1 book.

Find Subnet IDs, Problem Set 1: 8 or Fewer Subnet Bits

The problems, which consist of a classful network and static-length mask, are as follows:

1. 172.32.0.0/22
2. 200.1.2.0/28
3. 10.0.0.0/15
4. 172.20.0.0/24

Find Subnet IDs, Problem Set 2: More Than 8 Subnet Bits

The problems, which consist of a classful network and static-length mask, are as follows:

1. 172.32.0.0/25
2. 10.0.0.0/21

Answers to Find Subnet IDs, Problem Set 1

This section includes the answers to the four problems listed in Problem Set 1.

Problem Set 1, Answer 1: 172.32.0.0/22

The answer is as follows:

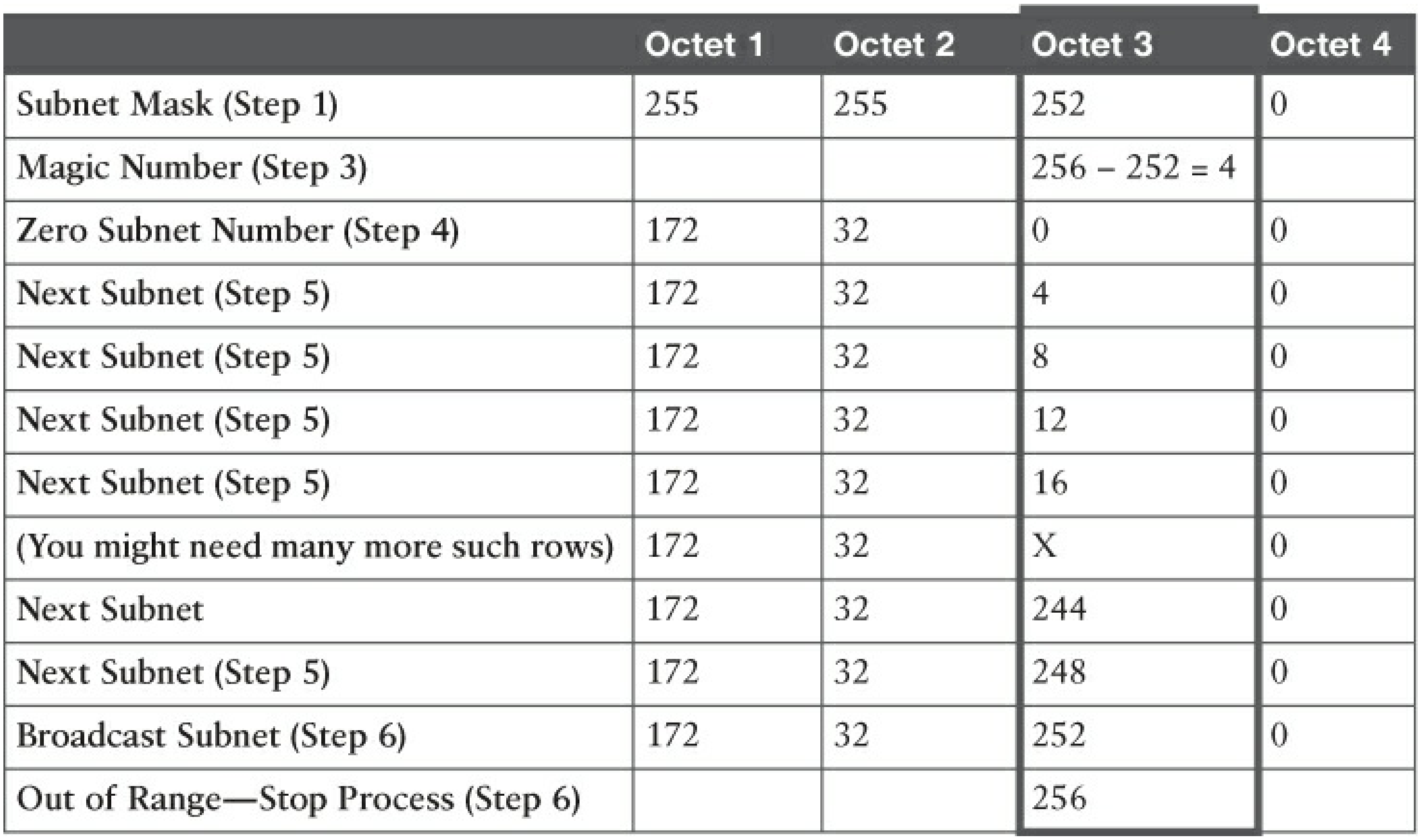
- 172.32.0.0 (zero subnet)
- 172.32.4.0
- 172.32.8.0
- 172.32.12.0
- 172.32.16.0
- 172.32.20.0
- 172.32.24.0

  (Skipping many subnets; each new subnet is the same as the previous subnet, after adding 4 to the third octet.) ■ 172.32.248.0
- 172.32.252.0 (broadcast subnet) The process to find all subnets depends on three key pieces of information:
- The mask has fewer than 8 subnet bits (6 bits), because the network is a Class B network (16 network bits), and the mask has 22 binary 1s in it—implying 10 host bits and leaving 6 subnet bits.
- The mask in dotted-decimal format is 255.255.252.0. The interesting octet is the third octet because the subnet bits are all in the third octet.
- Each successive subnet number is 4 higher than the previous subnet number, in the interesting octet, because the magic number is 256 – 252 = 4.

As a result, in this case, all the subnets begin with 172.32, have a multiple of 4 in the third octet, and end in 0.

Table G-2 shows the results of the various steps of the process, as outlined in Chapter 19.

Table G-2. 8 or Fewer Subnet Bits, Question 1: Answer Table



	Octet 1	Octet 2	Octet 3	Octet 4
Subnet Mask (Step 1)	255	255	252	0
Magic Number (Step 3)			256 – 252 = 4	
Zero Subnet Number (Step 4)	172	32	0	0
Next Subnet (Step 5)	172	32	4	0
Next Subnet (Step 5)	172	32	8	0
Next Subnet (Step 5)	172	32	12	0
Next Subnet (Step 5)	172	32	16	0
(You might need many more such rows)	172	32	X	0
Next Subnet	172	32	244	0
Next Subnet (Step 5)	172	32	248	0
Broadcast Subnet (Step 6)	172	32	252	0
Out of Range—Stop Process (Step 6)			256	

Problem Set 1, Answer 2: 200.1.2.0/28

The answer is as follows:

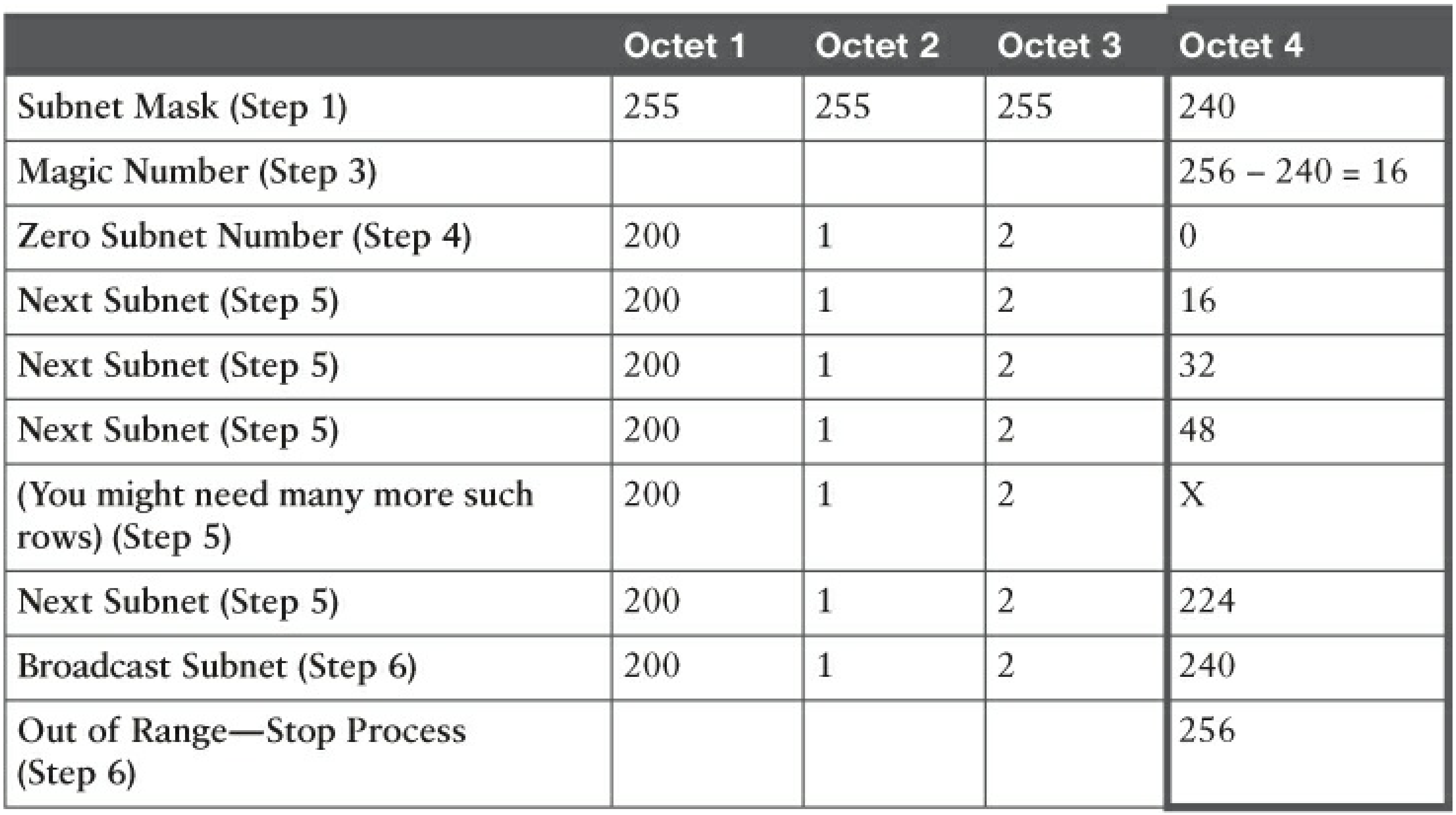
- 200.1.2.0 (zero subnet)
- 200.1.2.16
- 200.1.2.32
- 200.1.2.48
- 200.1.2.64
- 200.1.2.80

  (Skipping many subnets; each new subnet is the same as the previous subnet, after adding 16 to the fourth octet.) ■ 200.1.2.224
- 200.1.2.240 (broadcast subnet) The process to find all subnets depends on three key pieces of information, as follows:
- The mask has fewer than 8 subnet bits (4 bits), because the network is a Class C network (24 network bits), and the mask has 28 binary 1s in it, which implies 4 host bits and leaves 4 subnet bits.
- The mask in dotted-decimal format is 255.255.255.240. The interesting octet is the fourth octet, because all the subnet bits are in the fourth octet.
- Each successive subnet number is 16 higher than the previous subnet number, in the interesting octet, because the magic number is 256 – 240 = 16.

As a result, in this case, all the subnets begin with 200.1.2 and have a multiple of 16 in the fourth octet.

Table G-3 shows the results of the various steps of the process, as outlined in Chapter 19.

Table G-3. Problem Set 1, Question 2: Answer Table



	Octet 1	Octet 2	Octet 3	Octet 4
Subnet Mask (Step 1)	255	255	255	240
Magic Number (Step 3)				256 – 240 = 16
Zero Subnet Number (Step 4)	200	1	2	0
Next Subnet (Step 5)	200	1	2	16
Next Subnet (Step 5)	200	1	2	32
Next Subnet (Step 5)	200	1	2	48
(You might need many more such rows) (Step 5)	200	1	2	X
Next Subnet (Step 5)	200	1	2	224
Broadcast Subnet (Step 6)	200	1	2	240
Out of Range—Stop Process (Step 6)				256

Problem Set 1, Answer 3: 10.0.0.0/15

The answer is as follows:

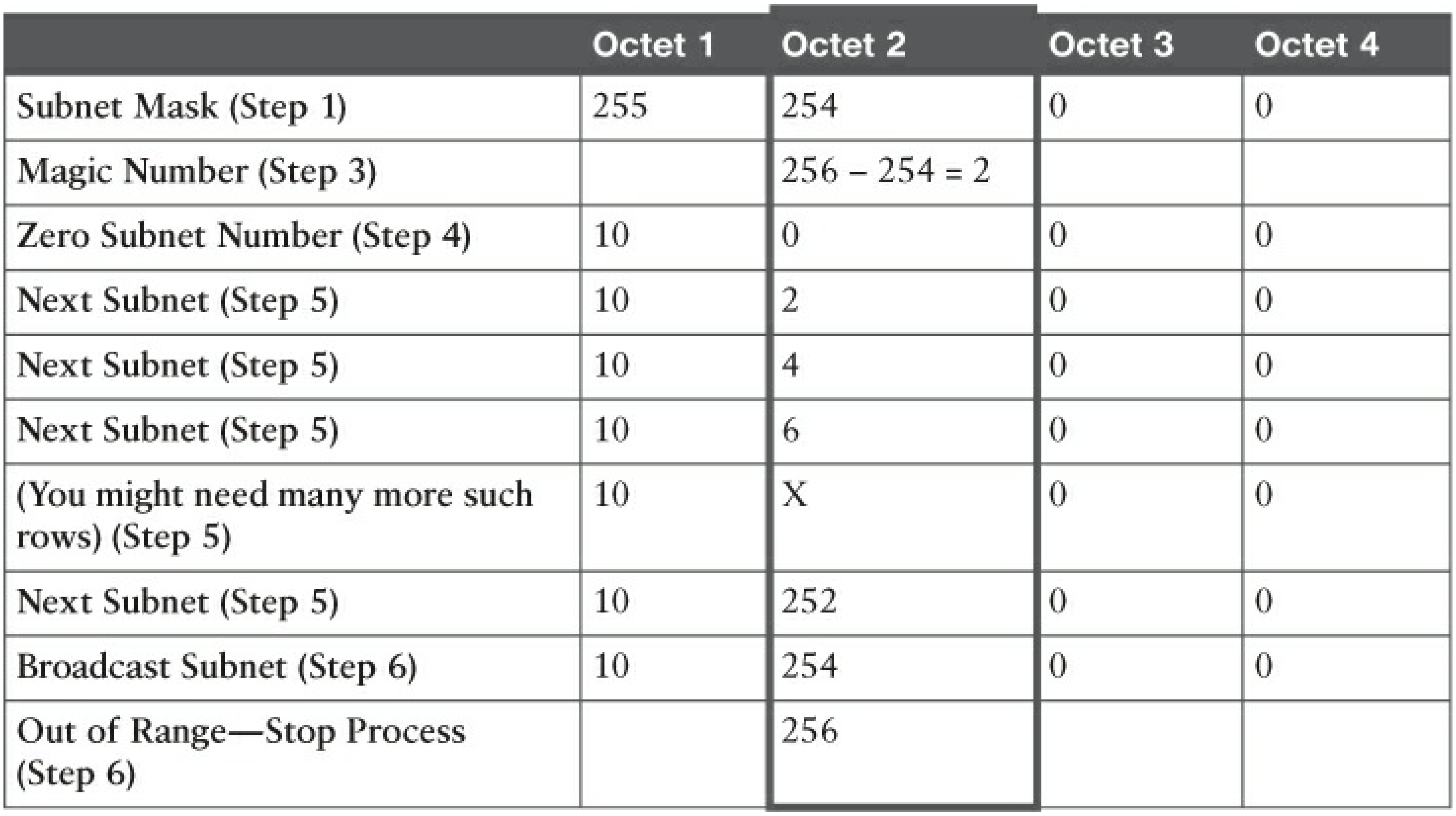
- 10.0.0.0 (zero subnet)
- 10.2.0.0
- 10.4.0.0
- 10.6.0.0

  (Skipping many subnets; each new subnet is the same as the previous subnet, after adding 2 to the second octet.) ■ 10.252.0.0
- 10.254.0.0 (broadcast subnet) The process to find all subnets depends on three key pieces of information:
- The mask has fewer than 8 subnet bits (7 subnet bits), because the network is a Class A network (8 network bits), and the mask has 15 binary 1s in it, which implies 17 host bits and leaves 7 subnet bits.
- The mask in dotted-decimal format is 255.254.0.0. The interesting octet is the second octet, because all the subnet bits exist in the second octet.
- Each successive subnet number is 2 higher than the previous subnet number, in the interesting octet, because the magic number is 256 – 254 = 2.

As a result, in this case, all the subnets begin with 10, have a multiple of 2 in the second octet, and end in 0.0.

Table G-4 shows the results of the various steps of the process, as outlined in Chapter 19.

Table G-4. Problem Set 1, Question 3: Answer Table



	Octet 1	Octet 2	Octet 3	Octet 4
Subnet Mask (Step 1)	255	254	0	0
Magic Number (Step 3)		256 – 254 = 2		
Zero Subnet Number (Step 4)	10	0	0	0
Next Subnet (Step 5)	10	2	0	0
Next Subnet (Step 5)	10	4	0	0
Next Subnet (Step 5)	10	6	0	0
(You might need many more such rows) (Step 5)	10	X	0	0
Next Subnet (Step 5)	10	252	0	0
Broadcast Subnet (Step 6)	10	254	0	0
Out of Range—Stop Process (Step 6)		256		

Problem Set 1, Answer 4: 172.20.0.0/24

This problem has an 8-bit subnet field, meaning that 2^8, or 256, possible subnets exist. The following list shows some of the subnets, which should be enough to see the trends in how to find all subnet numbers:

- 172.20.0.0 (zero subnet)
- 172.20.1.0
- 172.20.2.0
- 172.20.3.0
- 172.20.4.0

  (Skipping many subnets; each new subnet is the same as the previous subnet, after adding 1 to the third octet.) ■ 172.20.252.0
- 172.20.253.0
- 172.20.254.0
- 172.20.255.0 (broadcast subnet) The process to find all subnets depends on three key pieces of information:
- The mask has exactly 8 subnet bits, specifically all bits in the third octet, making the third octet the interesting octet.
- The magic number is 256 – 255 = 1, because the mask's value in the interesting (third) octet is 255.
- Beginning with the network number of 172.20.0.0, which is the same value as the zero subnet, just add the magic number (1) in the interesting octet.

Essentially, you just count by 1 in the third octet until you reach the highest legal number (255). The first subnet, 172.20.0.0, is the zero subnet, and the last subnet, 172.20.255.0, is the broadcast subnet.

Answers to Find Subnet IDs, Problem Set 2

Problem Set 2, Answer 1: 172.32.0.0/25

This problem has a 9-bit subnet field, meaning that 2^9, or 512, possible subnets exist. The following list shows some of the subnets, which should be enough to see the trends in how to find all subnet numbers: ■ 172.32.0.0 (zero subnet)

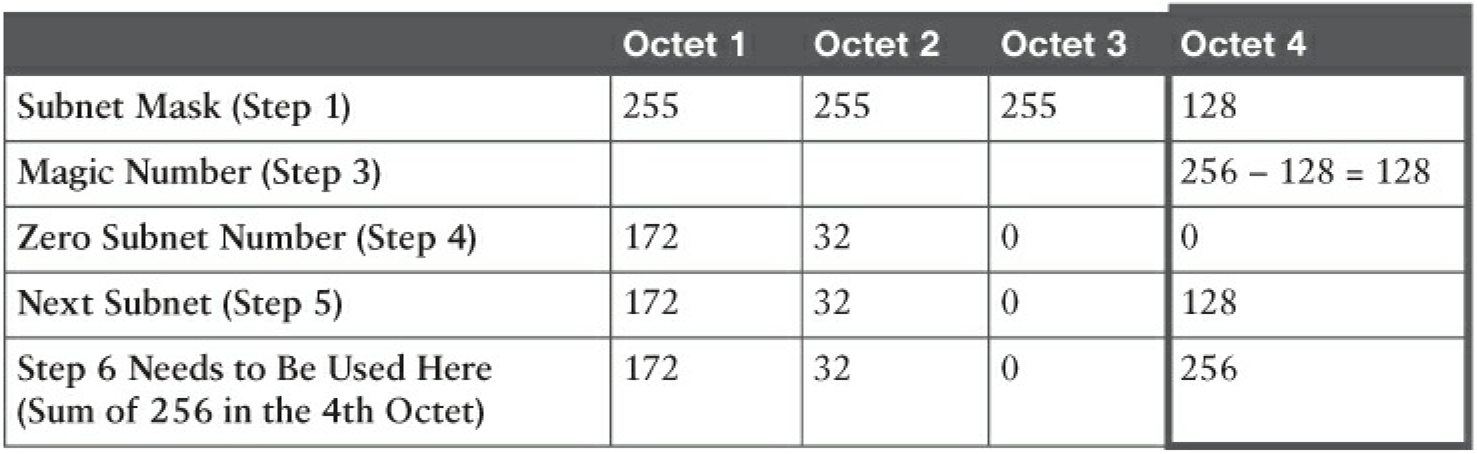
- 172.32.0.128
- 172.32.1.0
- 172.32.1.128
- 172.32.2.0
- 172.32.2.128
- 172.32.3.0
- 172.32.3.128

  (Skipping many subnets; the subnets occur in blocks of two, with either 0 or 128 in the fourth octet, with each successive block being one greater in the third octet.) ■ 172.32.254.0

- 172.32.254.128
- 172.32.255.0
- 172.32.255.128 (broadcast subnet) The process to find all subnets depends on three key pieces of information, as follows:
- The mask has more than 8 subnet bits (9 bits), because the network is a Class B network (16 network bits), and the mask has 25 binary 1s in it, which implies 7 host bits and leaves 9 subnet bits.
- Using the terminology in Chapter 19 of the ICND1 book, octet 4 is the interesting octet, where the counting occurs based on the magic number. Octet 3 is the "just left" octet, in which the process counts by 1, from 0 to 255.
- The magic number, which will be used to calculate each successive subnet number, is 256 – 128 = 128.

To calculate the first subnet block, use the same six-step process as used in the simpler problems that have 8 or fewer subnet bits. In this case, with only 1 subnet bit in octet 4, only two subnets exist in each subnet block. Table G-5 shows the steps as compared to the six-step process to find the subnets in a subnet block.

Table G-5. Creating the First Subnet Block



	Octet 1	Octet 2	Octet 3	Octet 4
Subnet Mask (Step 1)	255	255	255	128
Magic Number (Step 3)				256 – 128 = 128
Zero Subnet Number (Step 4)	172	32	0	0
Next Subnet (Step 5)	172	32	0	128
Step 6 Needs to Be Used Here (Sum of 256 in the 4th Octet)	172	32	0	256

The table represents the logic, but to make sure that the answer is clear, the first subnet block includes the following: 172.32.0.0

172.32.0.128

The next major task—to create subnet blocks for all possible values in the "just left" octet—completes the process. Essentially, create 256 blocks like the previous list. The first has a value of 0, in the "just left" octet; the next has a value of 1; the next, a value of 2; and so on, through a block that begins with 172.30.255. Figure G-1 shows the concept.

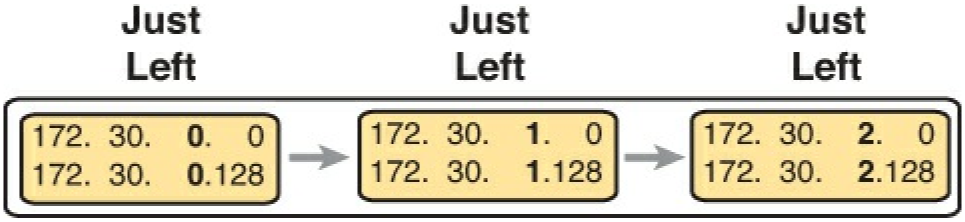


Figure G-1. Creating Subnet Blocks by Adding 1 in the "Just Left" Octet

Problem Set 2, Answer 2: 10.0.0.0/21

This problem has a 13-bit subnet field, meaning that 2^{13}, or 8192, possible subnets exist. The following list shows some of the subnets, which should be enough to see the trends in how to find all subnet numbers:

- 10.0.0.0 (zero subnet)
- 10.0.8.0
- 10.0.16.0
- 10.0.24.0

  (Skipping several subnets)
- 10.0.248.0
- 10.1.0.0
- 10.1.8.0
- 10.1.16.0

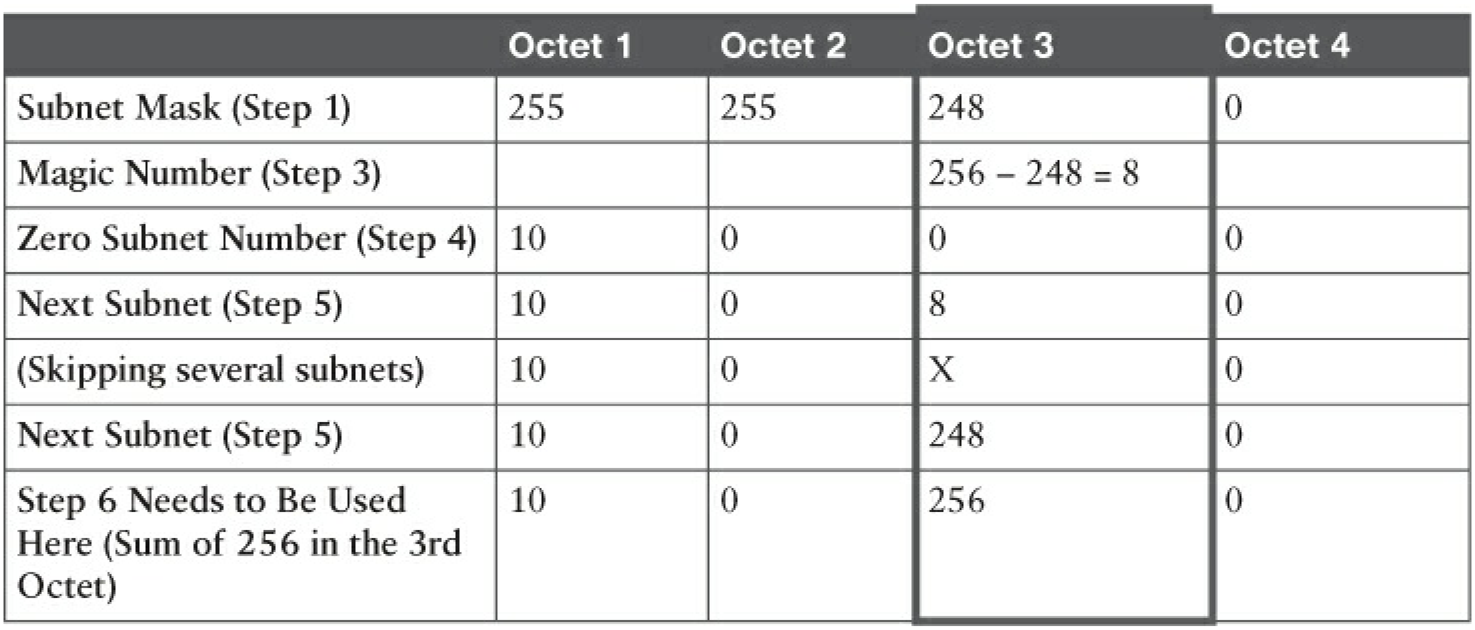
  (Skipping several subnets)
- 10.1.248.0
- 10.2.0.0

- 10.2.8.0
- 10.2.16.0

  (Skipping several subnets)
- 10.255.232.0
- 10.255.240.0
- 10.255.248.0 (broadcast subnet) The process to find all subnets depends on three key pieces of information, as follows:
- The mask has more than 8 subnet bits (13 bits), because the network is a Class A network (8 network bits), and the mask has 21 binary 1s in it, which implies 11 host bits and leaves 13 subnet bits.
- Using the terminology in Chapter 19 of the ICND1 book, octet 3 is the interesting octet, where the counting occurs based on the magic number. Octet 2 is the "just left" octet, in which the process counts by 1, from 0 to 255.
- The magic number, which will be used to calculate each successive subnet number, is 256 – 248 = 8.

To calculate the first subnet block, use the same six-step process as used in the simpler problems that have 8 or fewer subnet bits. In this case, with 5 subnet bits in octet 3, 32 subnets exist in each subnet block. Table G-6 shows the steps as compared to the six-step process to find the subnets in a subnet block.

Table G-6. Creating the First Subnet Block



	Octet 1	Octet 2	Octet 3	Octet 4
Subnet Mask (Step 1)	255	255	248	0
Magic Number (Step 3)			256 – 248 = 8	
Zero Subnet Number (Step 4)	10	0	0	0
Next Subnet (Step 5)	10	0	8	0
(Skipping several subnets)	10	0	X	0
Next Subnet (Step 5)	10	0	248	0
Step 6 Needs to Be Used Here (Sum of 256 in the 3rd Octet)	10	0	256	0

The table represents the logic, but to make sure that the answer is clear, the first subnet block includes the following: 10.0.0.0

10.0.8.0
10.0.16.0
10.0.24.0
10.0.32.0
10.0.40.0
10.0.48.0
10.0.56.0
10.0.64.0
And so on...
10.0.248.0

The next major task—to create subnet blocks for all possible values in the "just left" octet—completes the process. Essentially, create 256 blocks like the previous list. The first has a value of 0, in the "just left" octet; the next has a value of 1; the next, a value of 2; and so on, through a block that begins with 10.255. Figure G-2 shows the concept.

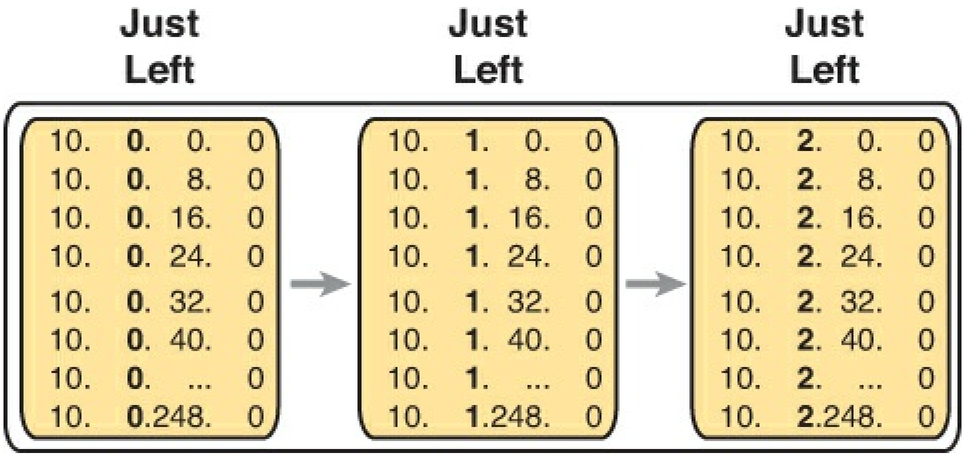

Just Left
Just Left
Just Left
10. 0. 0. 0
10. 0. 8. 0
10. 0. 16. 0
10. 0. 24. 0
10. 0. 32. 0
10. 0. 40. 0
10. 0. ... 0
10. 0.248. 0
10. 1. 0. 0
10. 1. 8. 0
10. 1. 16. 0
10. 1. 24. 0
10. 1. 32. 0
10. 1. 40. 0
10. 1. ... 0
10. 1.248. 0
10. 2. 0. 0
10. 2. 8. 0
10. 2. 16. 0
10. 2. 24. 0
10. 2. 32. 0
10. 2. 40. 0
10. 2. ... 0
10. 2.248. 0

Figure G-2. Creating Subnet Blocks by Adding 1 in the "Just Left" Octet

Appendix H. Practice for Chapter 20: Variable-Length Subnet Masks

Practice Problems

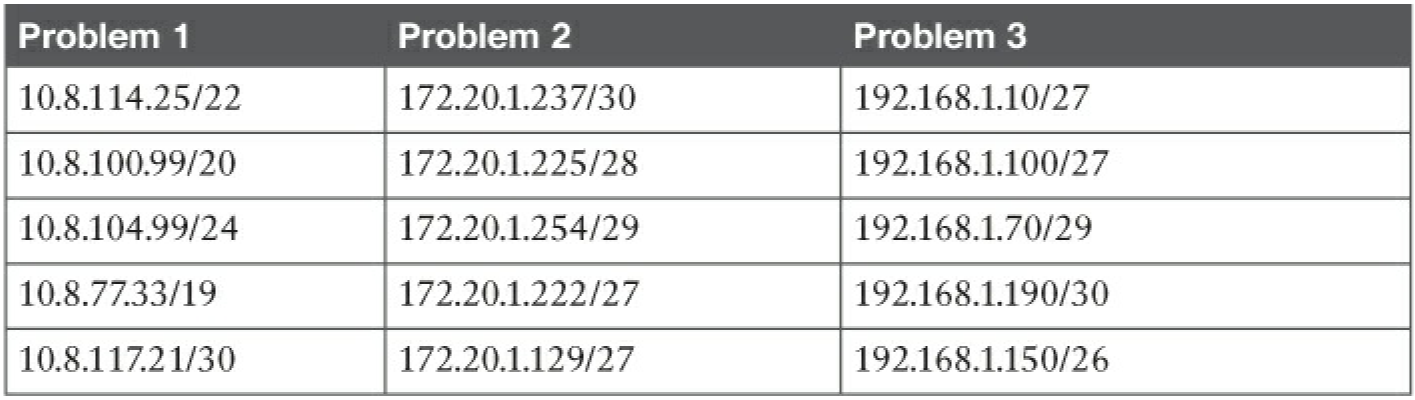
This appendix includes two varieties of VLSM practice problems related to Chapter 20, "Variable-Length Subnet Masks." The first type of problem lists pairs of IP addresses and masks from a network, and your job is to discover whether any of the subnets implied by those addresses/masks overlap. The second problem starts with a list of existing subnets, and your job is to find the numerically lowest new subnet ID that could be added to that internetwork for a given mask.

Note that you can find additional practice at the author's CCENT and CCNA blog, which is linked from the author's website, www.certskills.com.

Practice Finding VLSM Overlaps

Table H-1 lists three practice problems where you can look for VLSM overlaps. Start with the five IP addresses listed in a single column, and then follow the three-step process outlined in Chapter 20 to find any VLSM overlaps. The answers can be found later in this appendix, in the section "Answers to Practice Finding VLSM Overlap Problems."

Table H-1. VLSM Overlap Practice Problems



Problem 1	Problem 2	Problem 3
10.8.114.25/22	172.20.1.237/30	192.168.1.10/27
10.8.100.99/20	172.20.1.225/28	192.168.1.100/27
10.8.104.99/24	172.20.1.254/29	192.168.1.70/29
10.8.77.33/19	172.20.1.222/27	192.168.1.190/30
10.8.117.21/30	172.20.1.129/27	192.168.1.150/26

Practice Adding New VLSM Subnets

Your boss wants you to add a subnet to an existing design. The existing design already has these five subnets:

172.16.0.0/20
172.16.20.0/22
172.16.32.0/21
172.16.18.240/30
172.16.18.0/28

The boss cannot decide among five competing subnet masks. However, the boss wants you to practice VLSM and plan the subnet ID he would use for each of those five possible masks. He tells you that the new subnet ID must be part of Class B network 172.16.0.0, that the new subnet must not overlap with the original five subnets, and that the new subnet ID must be the numerically lowest possible subnet ID (without breaking the other rules). Pick the one subnet ID you would plan to use based on each of the following mask choices by the boss:

1. /30
2. /23
3. /21
4. /26
5. /20

The answers appear later in this appendix, in the section "Answers to Practice Adding New VLSM Subnets Problems."

Answers

Answers to Practice Finding VLSM Overlap Problems

This section lists the answers to the three practice problems in the section "Practice Finding VLSM Overlaps," listed earlier in Table H-1. Note that the tables that list details of the answer reordered the subnets as part of the process.

In Problem 1, the second and third subnet IDs listed in Table H-2 happen to overlap. The second subnet's range completely includes the range of addresses in the third subnet.

Table H-2. VLSM Overlap Problem 1 Answers (Overlaps Highlighted)

Reference	Original Address and Mask	Subnet ID	Broadcast Address
1	10.8.77.33/19	10.8.64.0	10.8.95.255
2	10.8.100.99/20	10.8.96.0	10.8.111.255
3	10.8.104.99/24	10.8.104.0	10.8.104.255
4	10.8.114.25/22	10.8.112.0	10.8.115.255
5	10.8.117.21/30	10.8.117.20	10.8.117.23

In Problem 2, the third and fourth subnets in Table H-3, listed in sequential order by subnet ID, overlap. The third subnet's range completely includes the range of addresses in the fourth subnet. Also, the two overlapping subnets have the same subnet broadcast address, making the overlap more obvious.

Table H-3. VLSM Overlap Problem 2 Answers (Overlaps Highlighted)

Reference	Original Address and Mask	Subnet ID	Broadcast Address
1	172.20.1.129/27	172.20.1.128	172.20.1.159
2	172.20.1.222/27	172.20.1.192	172.20.1.223
3	172.20.1.225/28	172.20.1.224	172.20.1.239
4	172.20.1.237/30	172.20.1.236	172.20.1.239
5	172.20.1.254/29	172.20.1.248	172.20.1.255

In Problem 3, the last two subnets in Table H-4, listed in sequential order by subnet ID, overlap.

Table H-4. VLSM Overlap Problem 3 Answers (Overlaps Highlighted)

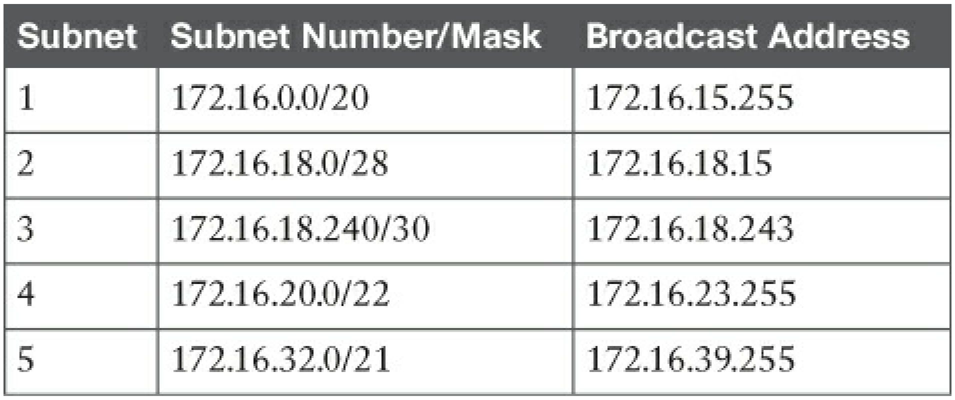
Reference	Original Address and Mask	Subnet ID	Broadcast Address
1	192.168.1.10/27	192.168.1.0	192.168.1.31
2	192.168.1.70/29	192.168.1.64	192.168.1.71
3	192.168.1.100/27	192.168.1.96	192.168.1.127
4	192.168.1.150/26	192.168.1.128	192.168.1.191
5	192.168.1.190/30	192.168.1.188	192.168.1.191

Answers to Practice Adding New VLSM Subnets Problems

This section lists the answers to the five practice problems in the earlier section "Practice Adding New VLSM Subnets."

All five problems for this section used the same set of five preexisting subnets. Table H-5 lists those subnet IDs and subnet broadcast addresses, in sequential order based on subnet ID. The list defines the lower and higher end of the range of numbers in each subnet.

Table H-5. Preexisting Subnets for the Add a VLSM Subnet Problems in This Appendix



Subnet	Subnet Number/Mask	Broadcast Address
1	172.16.0.0/20	172.16.15.255
2	172.16.18.0/28	172.16.18.15
3	172.16.18.240/30	172.16.18.243
4	172.16.20.0/22	172.16.23.255
5	172.16.32.0/21	172.16.39.255

The rest of the explanations follow the five-step process outlined in Chapter 20 in the section, “Adding a New Subnet to an Existing VLSM Design,” except that the explanations ignore Step 3, because Step 3’s results in each case are already listed in Table H-5.

Problem 1

Step 1. The problem statement tells us to use /30.

Step 2. The subnets would be 172.16.0.0, 172.16.0.4, 172.16.0.8, and so on, counting by 4 in the fourth octet and counting by 1 in the third octet.

Step 4. Many possible /30 subnets overlap: all 64 that begin 172.16.0, all 64 that begin 172.16.1, and so on, through all the subnets that begin 172.16.15 because the first existing somewhat-large subnet has a range from 172.16.0.0 to 172.16.15.255.

Step 5. 172.16.16.0/30 is the numerically lowest new subnet number that does not overlap with the existing subnets.

Problem 2

Step 1. The problem statement tells us to use /23.

Step 2. The subnets would be 172.16.0.0, 172.16.2.0, 172.16.4.0, 172.16.6.0, and so on, counting by 2 in the third octet.

Step 4. The first eight such subnets (through subnet 172.16.14.0/23) overlap with the first existing subnet. The first subnet ID that might not overlap would be 172.16.16.0, then 172.16.18.0, and so on.

Step 5. 172.16.16.0/23 is the numerically lowest new subnet number that does not overlap with the existing subnets.

Problem 3

Step 1. The problem statement tells us to use /21.

Step 2. The subnets would be 172.16.0.0, 172.16.8.0, 172.16.16.0, 172.16.24.0, and so on, counting by 8 in the third octet.

Step 4. The first two new possible subnets (172.16.0.0/21, 172.16.8.0/21) overlap with the first existing subnet. 172.16.16.0/21 overlaps with three other existing subnets, and 172.16.32.0/21 overlaps with the last subnet listed in Table H-5.

Step 5. 172.16.24.0/21 is the numerically lowest new subnet number that does not overlap with the existing subnets.

Problem 4

Step 1. The problem statement tells us to use /26.

Step 2. The subnets would be 172.16.0.0, 172.16.0.64, 172.16.0.128, 172.16.0.192, 172.16.1.0, 172.16.1.64, and so on, counting by 64 in the fourth octet and by 1 in the third octet.

Step 4. All the beginning /26 subnets overlap with the large first existing subnet (172.16.0.0/20). Although you could write down all the /26 subnets, you would need to write down 64 of these subnet numbers before getting to 172.16.16.0, which is the first number past the range for the first existing subnet.

Step 5. 172.16.16.0/26 is the numerically lowest new subnet number that does not overlap with the existing subnets.

Problem 5

Step 1. The problem statement tells us to use /20.

Step 2. The subnets would be 172.16.0.0, 172.16.16.0, 172.16.32.0, 172.16.48.0, 172.16.64.0, and so on, counting by 16 in the third octet.

Step 4. The first three subnets overlap with existing subnets per the details in Table H-5.

Step 5. 172.16.48.0/20 is the numerically lowest new subnet number that does not overlap with the existing subnets.

Appendix I. Practice for Chapter 21: Route Summarization

This appendix includes two features. First, it contains extra practice problems and answers related to Chapter 21, "Route Summarization," specifically about how to summarize routes. The second feature shows how to summarize routes using binary, as promised in Chapter 21, in case you want to understand what happens in binary when you summarize routes.

Note that you can find additional practice at the author's CCNA blog, which is linked from the author's website, www.certskills.com.

Practice Finding the Best Summary Route

Table I-1 lists four sets of subnets that need to be summarized as part of a summary route. Find the subnet number/mask combination that is the best summary route.

Table I-1. Practice Problems: Finding the Best Summary Route

Problem 1	Problem 2	Problem 3	Problem 4
10.100.200.0/23	172.21.100.0/23	172.22.100.0/25	192.168.2.128/28
10.100.192.0/21	172.21.104.0/23	172.22.98.0/25	192.168.2.160/29
10.100.204.0/24	172.21.106.0/23	172.22.99.0/25	192.168.2.152/30
10.100.190.0/23	172.21.102.0/23	172.22.101.128/25	192.168.2.156/30

Answers to Practice Problems

This section lists the answers to the practice problems along with a description of how to use the process in this book to solve the problems. For each problem, the first table lists the results of the first two steps; the grayed boxes show the low and high end of the range that the new summary route must enclose. The second table for each problem shows the results of each pass through Step 4, with the final (rightmost) pass showing the correct answer.

Practice Problem 1

Table I-2. Practice Problem 1: First Two Steps

Subnet IDs/Masks	Subnet Broadcasts
10.100.200.0	10.100.201.255
10.100.192.0	10.100.199.255
10.100.204.0	10.100.204.255
10.100.190.0	10.100.191.255

For Problem 1, at Step 3, the shortest mask is *21, so the initial mask will be one smaller, or* 20. Finding the correct answer requires four passes through calculating a new subnet ID and mask, with the final answer shown in Table I-3.

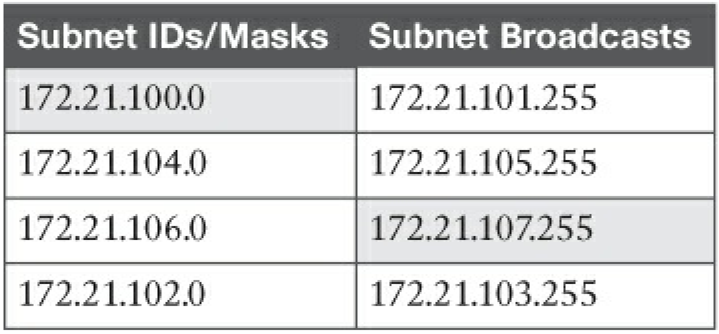
Table I-3. Practice Problem 1: Multiple Passes Through Step 4 (Correct Answer Highlighted)

All Passes Use 10.100.190.0	1st Pass: /20	2nd Pass: /19	3rd Pass: /18	4th Pass: /17
Subnet ID	10.100.176.0	10.100.160.0	10.100.128.0	10.100.128.0
Broadcast Address	10.100.191.255	10.100.191.255	10.100.191.255	10.100.255.255

The best summary route will use subnet ID 10.100.128.0, mask /17.

Practice Problem 2

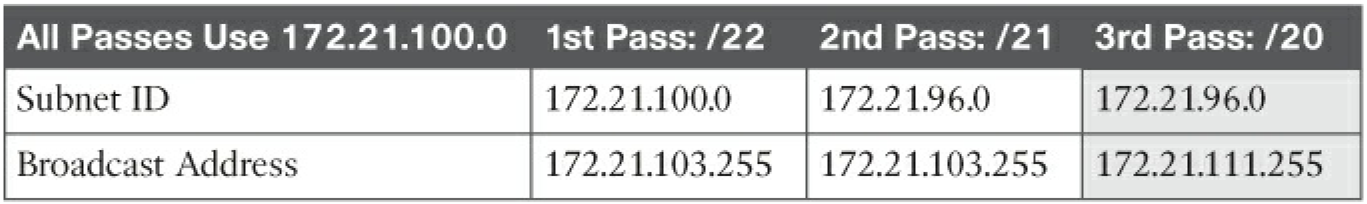
Table I-4. Practice Problem 2: First Two Steps



Subnet IDs/Masks	Subnet Broadcasts
172.21.100.0	172.21.101.255
172.21.104.0	172.21.105.255
172.21.106.0	172.21.107.255
172.21.102.0	172.21.103.255

For Problem 2, at Step 3, all the original masks are /23, so the initial mask will be one smaller, or /22. Finding the correct answer requires three passes through calculating a new subnet ID and mask, with the final answer shown in Table I-5.

Table I-5. Practice Problem 2: Multiple Passes Through Step 4 (Correct Answer Highlighted)

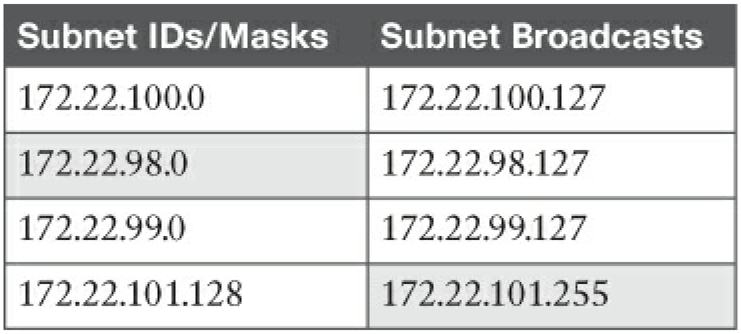


All Passes Use 172.21.100.0	1st Pass: /22	2nd Pass: /21	3rd Pass: /20
Subnet ID	172.21.100.0	172.21.96.0	172.21.96.0
Broadcast Address	172.21.103.255	172.21.103.255	172.21.111.255

The best summary route will use subnet ID 172.21.96.0, mask /20.

Practice Problem 3

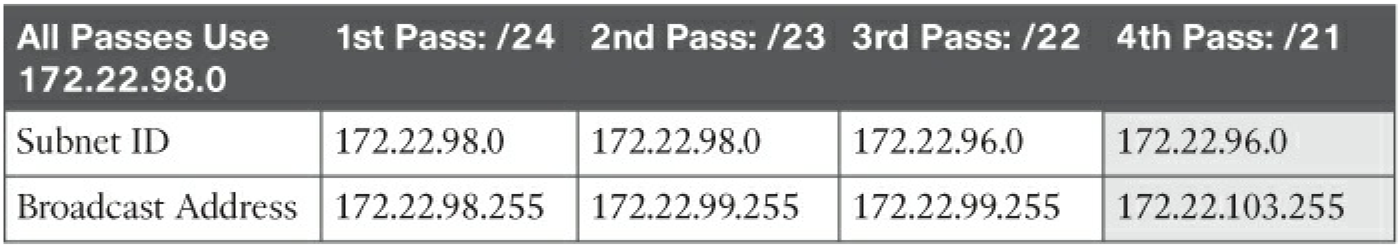
Table I-6. Practice Problem 3: First Two Steps



Subnet IDs/Masks	Subnet Broadcasts
172.22.100.0	172.22.100.127
172.22.98.0	172.22.98.127
172.22.99.0	172.22.99.127
172.22.101.128	172.22.101.255

For Problem 3, at Step 3, all the original masks are *25, so the initial mask will be one smaller, or* 24. Finding the correct answer requires four passes through calculating a new subnet ID and mask, with the final answer shown in Table I-7.

Table I-7. Practice Problem 3: Multiple Passes Through Step 4 (Correct Answer Highlighted)

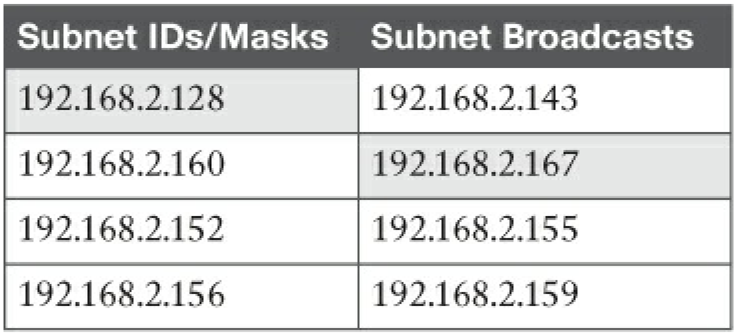


All Passes Use 172.22.98.0	1st Pass: /24	2nd Pass: /23	3rd Pass: /22	4th Pass: /21
Subnet ID	172.22.98.0	172.22.98.0	172.22.96.0	172.22.96.0
Broadcast Address	172.22.98.255	172.22.99.255	172.22.99.255	172.22.103.255

The best summary route will use subnet ID 172.22.96.0, mask /21.

Practice Problem 4

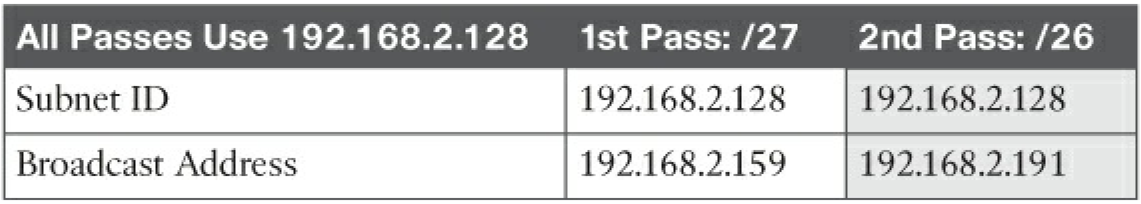
Table I-8. Practice Problem 4: First Two Steps



Subnet IDs/Masks	Subnet Broadcasts
192.168.2.128	192.168.2.143
192.168.2.160	192.168.2.167
192.168.2.152	192.168.2.155
192.168.2.156	192.168.2.159

For Problem 4, at Step 3, the shortest mask is /28, so the initial mask will be one smaller, or /27. Finding the correct answer requires only two passes through calculating a new subnet ID and mask, with the final answer shown in Table I-9.

Table I-9. Practice Problem 4: Multiple Passes Through Step 4 (Correct Answer Highlighted)



All Passes Use 192.168.2.128	1st Pass: /27	2nd Pass: /26
Subnet ID	192.168.2.128	192.168.2.128
Broadcast Address	192.168.2.159	192.168.2.191

The best summary route will use subnet ID 192.168.2.128, mask /26.

Appendix J. Practice for Chapter 22: Basic IPv4 Access Control Lists

Practice Problems

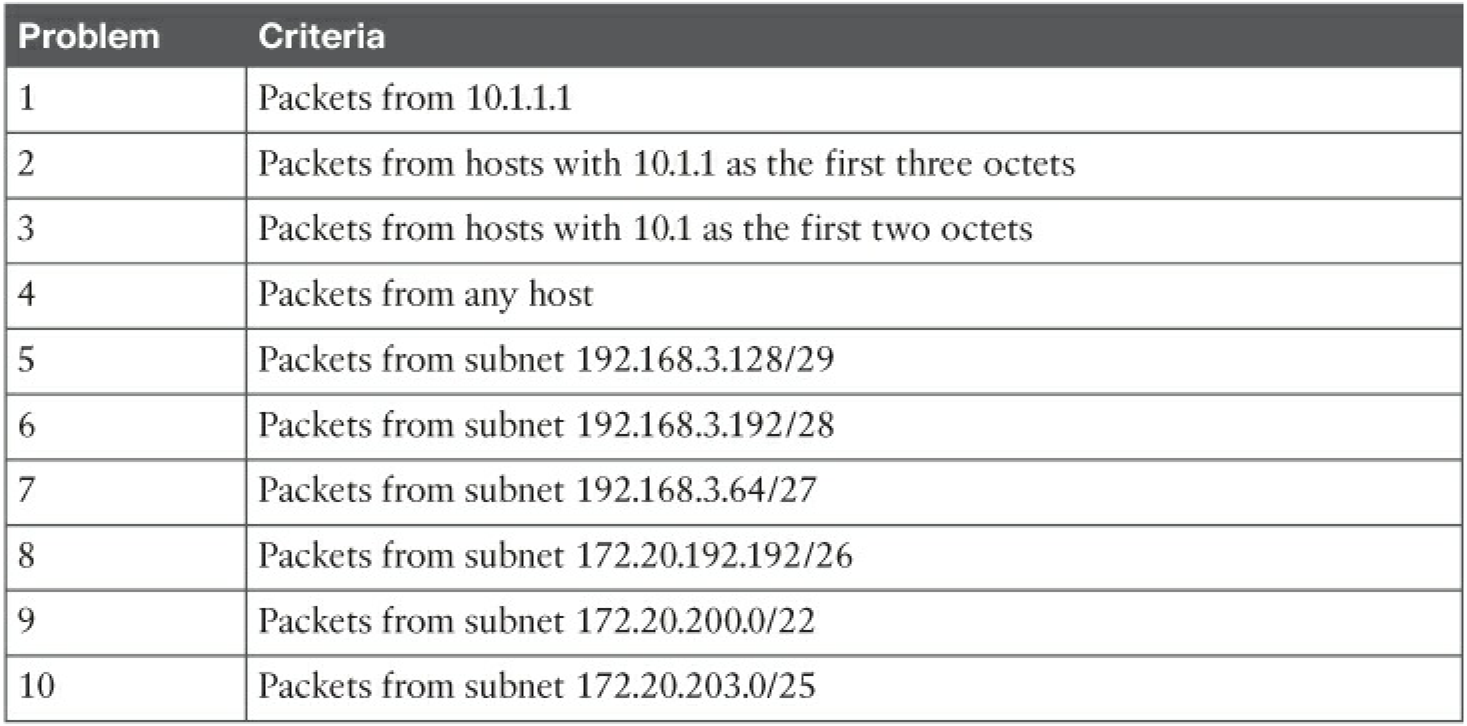
This appendix includes two sets of practice problems. The first question set lists requirements for a single-line access control list (ACL), with your task being to create a standard numbered ACL that meets the requirements. The second question set shows an existing **access-list** command, with your job being to determine the range of IP addresses matched by the ACL.

Note that you can find additional practice on the author's CCENT blog, which is linked from the author's website, www.certskills.com.

Practice Building access-list Commands

Table J-1 lists the criteria for several practice problems. Your job: Create a one-line standard ACL that matches the packets. The answers are listed later in this appendix.

Table J-1. Building One-Line Standard ACLs: Practice

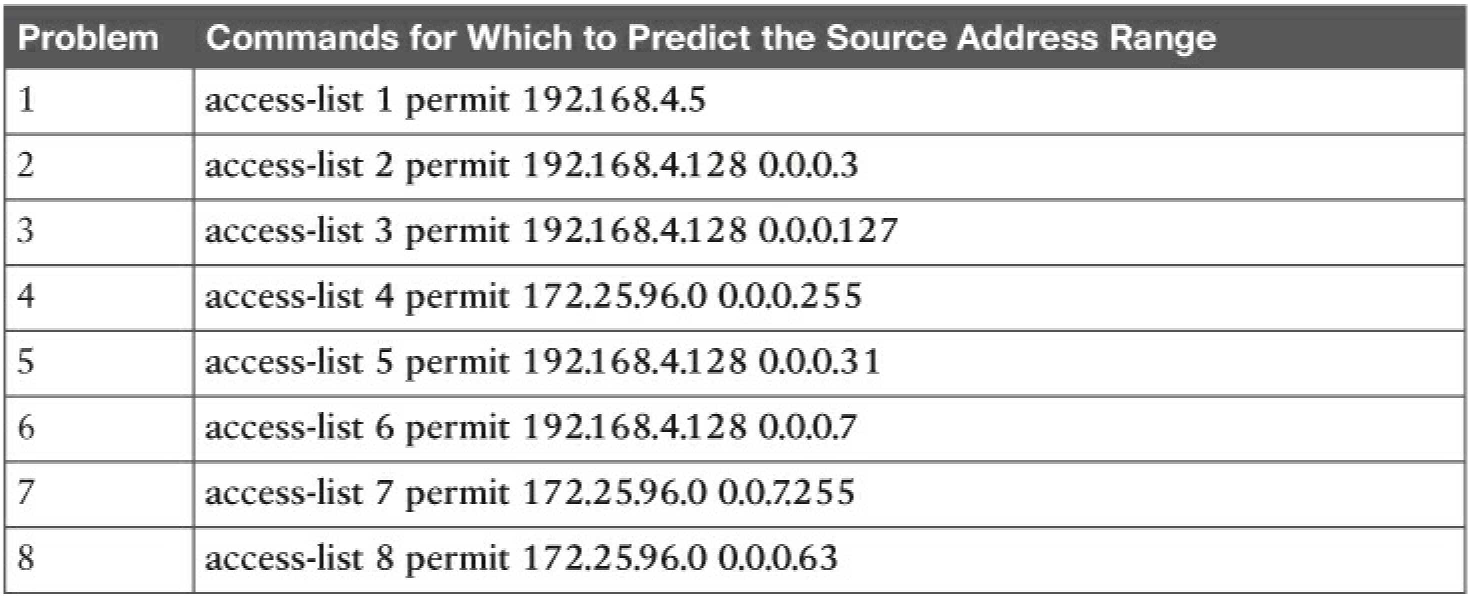


Problem	Criteria
1	Packets from 10.1.1.1
2	Packets from hosts with 10.1.1 as the first three octets
3	Packets from hosts with 10.1 as the first two octets
4	Packets from any host
5	Packets from subnet 192.168.3.128/29
6	Packets from subnet 192.168.3.192/28
7	Packets from subnet 192.168.3.64/27
8	Packets from subnet 172.20.192.192/26
9	Packets from subnet 172.20.200.0/22
10	Packets from subnet 172.20.203.0/25

Reverse Engineering from ACL to Address Range

For this second question set, look at the existing **access-list** commands in Table J-2. In each case, make a notation about the exact IP address, or range of IP addresses, matched by the command.

Table J-2. Finding IP Addresses/Ranges Matching by Existing ACLs



Problem	Commands for Which to Predict the Source Address Range
1	access-list 1 permit 192.168.4.5
2	access-list 2 permit 192.168.4.128 0.0.0.3
3	access-list 3 permit 192.168.4.128 0.0.0.127
4	access-list 4 permit 172.25.96.0 0.0.0.255
5	access-list 5 permit 192.168.4.128 0.0.0.31
6	access-list 6 permit 192.168.4.128 0.0.0.7
7	access-list 7 permit 172.25.96.0 0.0.7.255
8	access-list 8 permit 172.25.96.0 0.0.0.63

Note

You can only rely on the method of adding these numbers together (as shown in Chapter 22 of the ICND1 book) if you know that the **access-list** command comes from the router and specifically is not what someone simply wrote on a piece of paper. In this case, you can assume that the statements in Table J-2 came from a router.

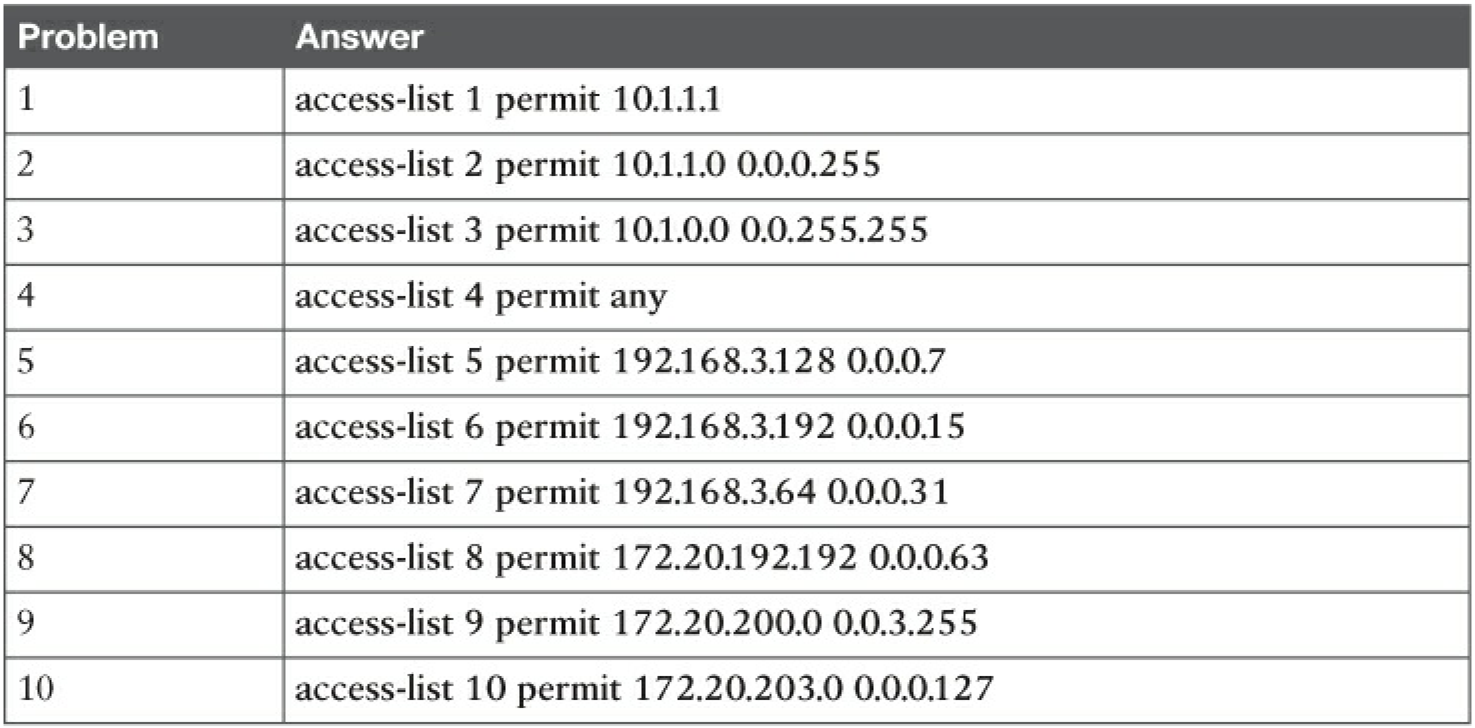
Answers to Earlier Practice Problems

This section contains the answers to the two sets of practice problems.

Answers: Practice Building access-list Commands

Table J-3 lists the answers to the problems listed in Table J-1.

Table J-3. Building One-Line Standard ACLs: Answers



Problem	Answer
1	access-list 1 permit 10.1.1.1
2	access-list 2 permit 10.1.1.0 0.0.0.255
3	access-list 3 permit 10.1.0.0 0.0.255.255
4	access-list 4 permit any
5	access-list 5 permit 192.168.3.128 0.0.0.7
6	access-list 6 permit 192.168.3.192 0.0.0.15
7	access-list 7 permit 192.168.3.64 0.0.0.31
8	access-list 8 permit 172.20.192.192 0.0.0.63
9	access-list 9 permit 172.20.200.0 0.0.3.255
10	access-list 10 permit 172.20.203.0 0.0.0.127

Answers: Reverse Engineering from ACL to Address Range

Table J-4 lists the answers to the problems listed in Table J-2.

Table J-4. Address Ranges for Problems in Table J-2: Answers

Problem	Address Range
1	One address: 192.168.4.5
2	192.168.4.128 – 192.168.4.131
3	192.168.4.128 – 192.168.4.255
4	172.25.96.0 – 172.25.96.255
5	192.168.4.128 – 192.168.4.159
6	192.168.4.128 – 192.168.4.135
7	172.25.96.0 – 172.25.103.255
8	172.25.96.0 – 172.25.96.63

Appendix K. Practice for Chapter 25: Fundamentals of IP Version 6

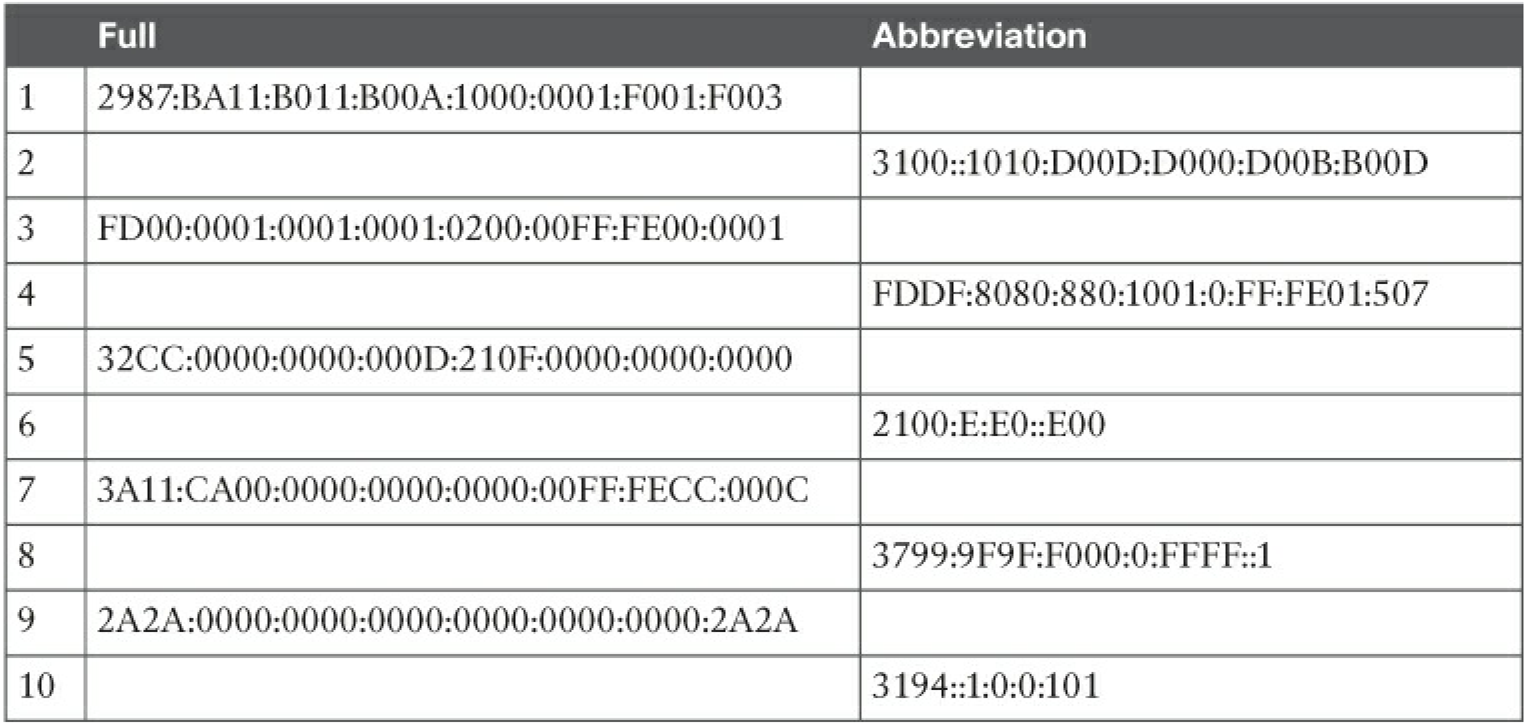
This appendix provides extra practice problems for two topics discussed in Chapter 25 of the book. The first problems let you convert from a full 32-digit IPv6 address to its abbreviated form, or to do the reverse. The second set of problems begins with IPv6 addresses and prefix lengths, asking you to determine the IPv6 prefix (subnet).

Address Abbreviating and Expanding Problems

Chapter 25 discusses some reasons why you may need to be able to mentally convert from the full 32-digit IPv6 address to the abbreviated form, or vice versa. The practice problems in this section simply provide more opportunities to practice.

Table K-1 lists some practice problems, with the full 32-digit IPv6 address on the left and the best abbreviation on the right. The table gives you either the expanded or abbreviated address, and you need to supply the opposite value. The answers sit at the end of the appendix, in the section "Answers to Address Abbreviating and Expansion Problems."

Table K-1. IPv6 Address Abbreviation and Expansion Practice



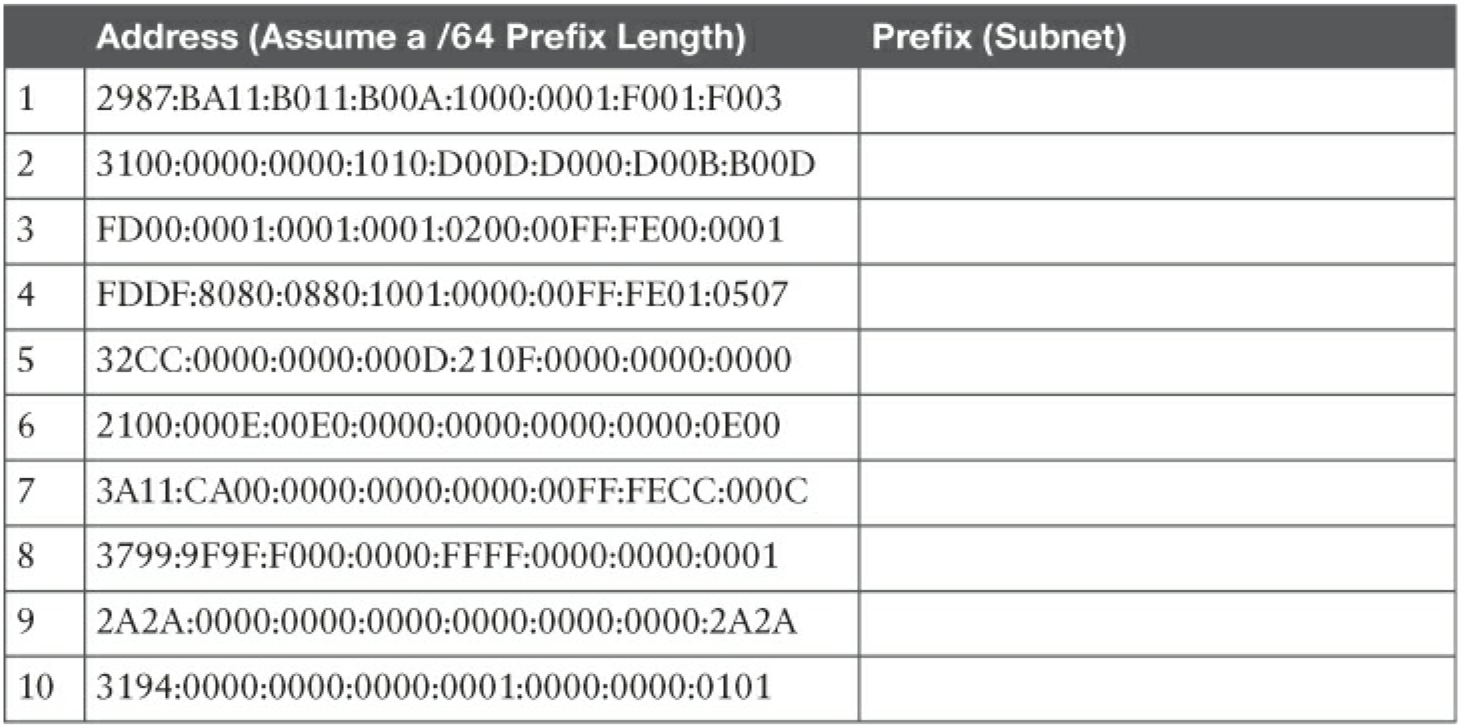
	Full	Abbreviation
1	2987:BA11:B011:B00A:1000:0001:F001:F003	
2		3100::1010:D00D:D000:D00B:B00D
3	FD00:0001:0001:0001:0200:00FF:FE00:0001	
4		FDDF:8080:880:1001:0:FF:FE01:507
5	32CC:0000:0000:000D:210F:0000:0000:0000	
6		2100:E:E0::E00
7	3A11:CA00:0000:0000:0000:00FF:FECC:000C	
8		3799:9F9F:F000:0:FFFF::1
9	2A2A:0000:0000:0000:0000:0000:0000:2A2A	
10		3194::1:0:0:101

Calculating the IPv6 Prefix Problems

Routers take the interface IPv6 address configuration and add a connected IPv6 route to the IPv6 routing table, for the IPv6 prefix (subnet) connected to that interface. This section provides some practice problems so that you can do the same math and predict the prefix value that the router will add to the routing table.

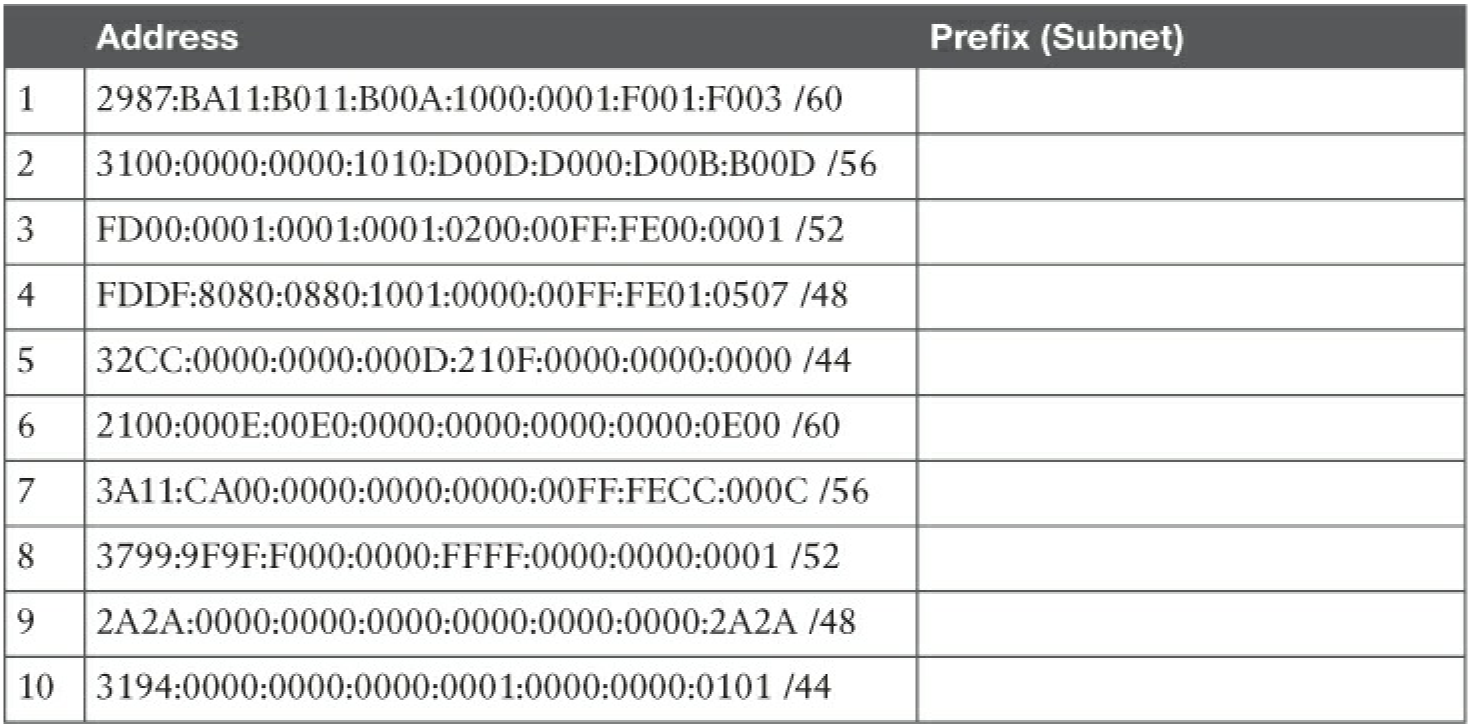
Table K-2 lists practice problems that all use the same prefix length (/64), which is the most common prefix length you see. Table K-3 that follows lists additional practice problems, with prefix lengths other than /64.

Table K-2. Finding the IPv6 Prefix When Using a /64 Prefix Length



	Address (Assume a /64 Prefix Length)	Prefix (Subnet)
1	2987:BA11:B011:B00A:1000:0001:F001:F003	
2	3100:0000:0000:1010:D00D:D000:D00B:B00D	
3	FD00:0001:0001:0001:0200:00FF:FE00:0001	
4	FDDF:8080:0880:1001:0000:00FF:FE01:0507	
5	32CC:0000:0000:000D:210F:0000:0000:0000	
6	2100:000E:00E0:0000:0000:0000:0000:0E00	
7	3A11:CA00:0000:0000:0000:00FF:FECC:000C	
8	3799:9F9F:F000:0000:FFFF:0000:0000:0001	
9	2A2A:0000:0000:0000:0000:0000:0000:2A2A	
10	3194:0000:0000:0000:0001:0000:0000:0101	

Table K-3. Finding the IPv6 Prefix Using a Prefix Length Other Than /64

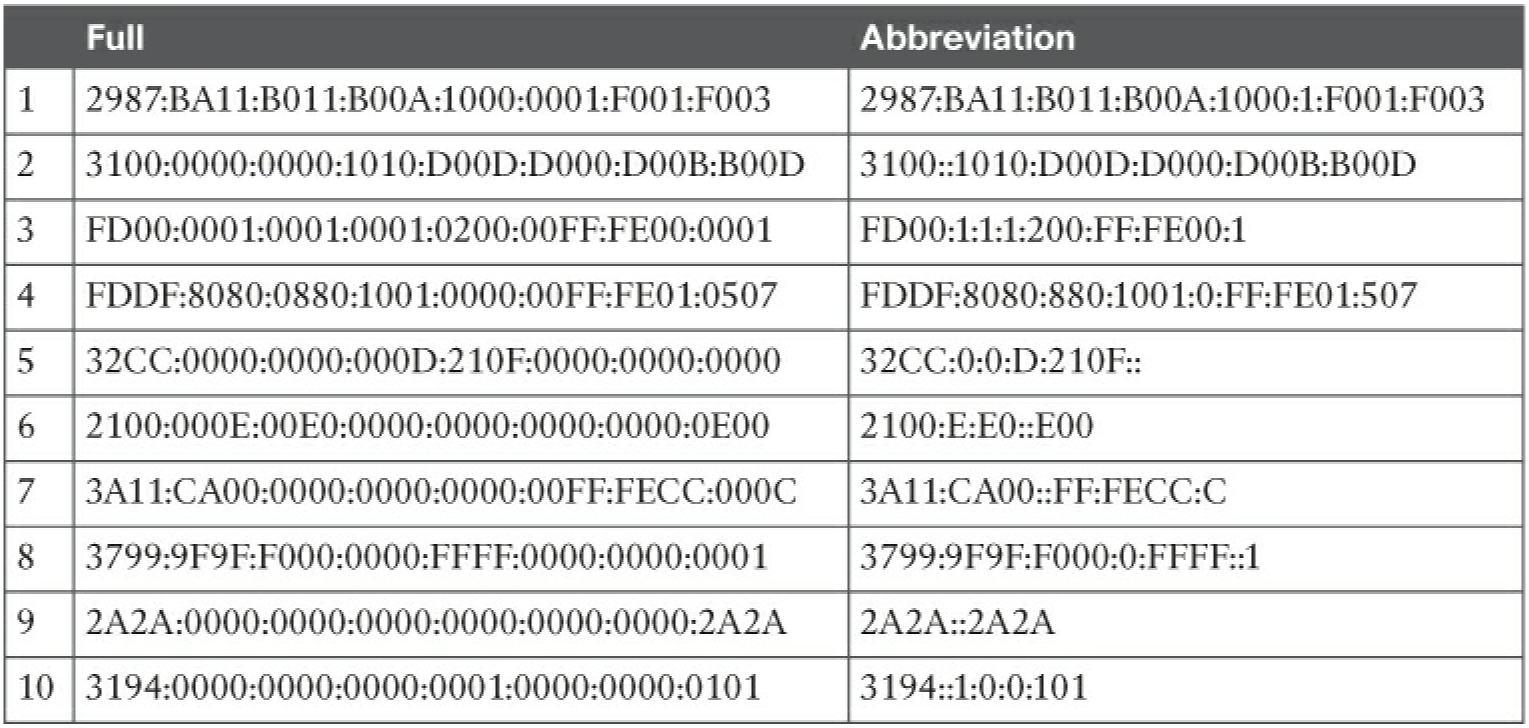


	Address	Prefix (Subnet)
1	2987:BA11:B011:B00A:1000:0001:F001:F003 /60	
2	3100:0000:0000:1010:D00D:D000:D00B:B00D /56	
3	FD00:0001:0001:0001:0200:00FF:FE00:0001 /52	
4	FDDF:8080:0880:1001:0000:00FF:FE01:0507 /48	
5	32CC:0000:0000:000D:210F:0000:0000:0000 /44	
6	2100:000E:00E0:0000:0000:0000:0000:0E00 /60	
7	3A11:CA00:0000:0000:0000:00FF:FECC:000C /56	
8	3799:9F9F:F000:0000:FFFF:0000:0000:0001 /52	
9	2A2A:0000:0000:0000:0000:0000:0000:2A2A /48	
10	3194:0000:0000:0000:0001:0000:0000:0101 /44	

Answers to Address Abbreviating and Expanding Problems

Table K-4 lists the answers to the problems listed earlier in Table K-1.

Table K-4. Answers: IPv6 Address Abbreviation and Expansion Practice

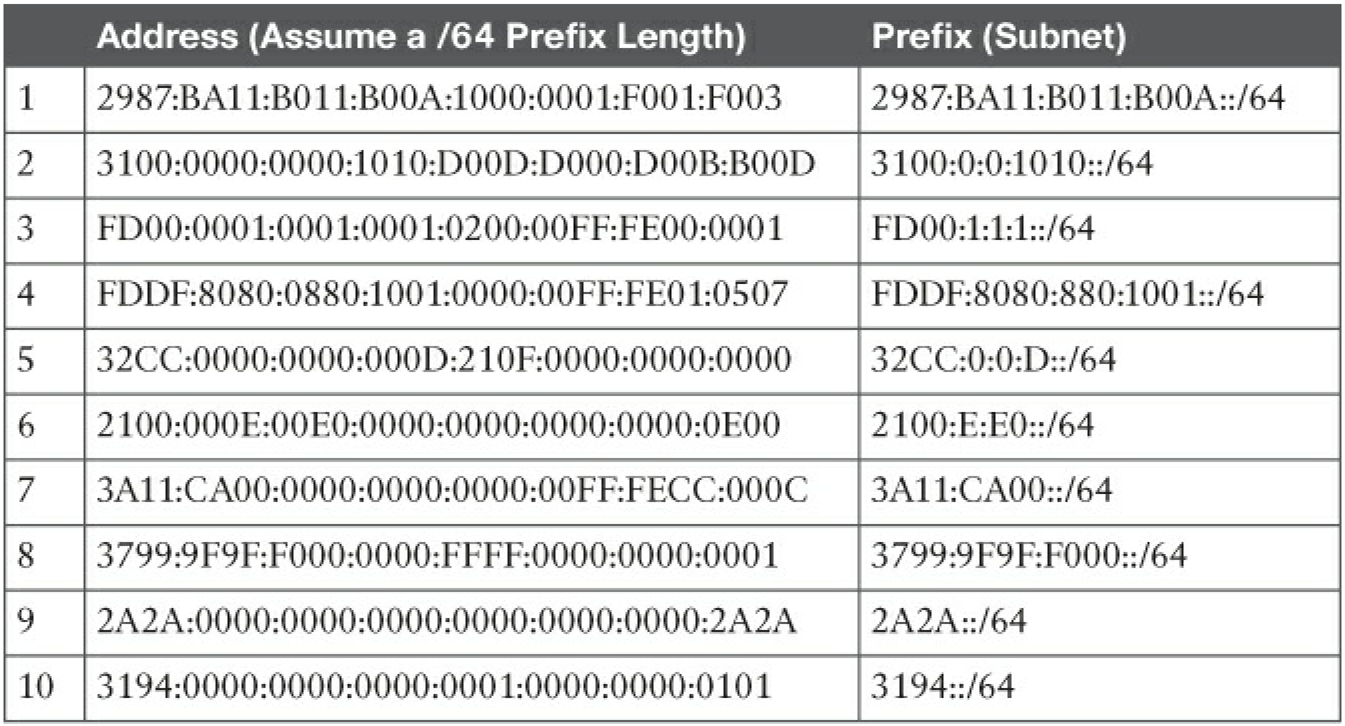


	Full	Abbreviation
1	2987:BA11:B011:B00A:1000:0001:F001:F003	2987:BA11:B011:B00A:1000:1:F001:F003
2	3100:0000:0000:1010:D00D:D000:D00B:B00D	3100::1010:D00D:D000:D00B:B00D
3	FD00:0001:0001:0001:0200:00FF:FE00:0001	FD00:1:1:1:200:FF:FE00:1
4	FDDF:8080:0880:1001:0000:00FF:FE01:0507	FDDF:8080:880:1001:0:FF:FE01:507
5	32CC:0000:0000:000D:210F:0000:0000:0000	32CC:0:0:D:210F::
6	2100:000E:00E0:0000:0000:0000:0000:0E00	2100:E:E0::E00
7	3A11:CA00:0000:0000:0000:00FF:FECC:000C	3A11:CA00::FF:FECC:C
8	3799:9F9F:F000:0000:FFFF:0000:0000:0001	3799:9F9F:F000:0:FFFF::1
9	2A2A:0000:0000:0000:0000:0000:0000:2A2A	2A2A::2A2A
10	3194:0000:0000:0000:0001:0000:0000:0101	3194::1:0:0:101

Answers to Calculating IPv6 Prefix Problems

Tables K-5 and K-6 list the answers to the problems listed earlier in Tables K-2 and K-3.

Table K-5. Answers: Finding the IPv6 Prefix, with a /64 Prefix Length



	Address (Assume a /64 Prefix Length)	Prefix (Subnet)
1	2987:BA11:B011:B00A:1000:0001:F001:F003	2987:BA11:B011:B00A::/64
2	3100:0000:0000:1010:D00D:D000:D00B:B00D	3100:0:0:1010::/64
3	FD00:0001:0001:0001:0200:00FF:FE00:0001	FD00:1:1:1::/64
4	FDDF:8080:0880:1001:0000:00FF:FE01:0507	FDDF:8080:880:1001::/64
5	32CC:0000:0000:000D:210F:0000:0000:0000	32CC:0:0:D::/64
6	2100:000E:00E0:0000:0000:0000:0000:0E00	2100:E:E0::/64
7	3A11:CA00:0000:0000:0000:00FF:FECC:000C	3A11:CA00::/64
8	3799:9F9F:F000:0000:FFFF:0000:0000:0001	3799:9F9F:F000::/64
9	2A2A:0000:0000:0000:0000:0000:0000:2A2A	2A2A::/64
10	3194:0000:0000:0000:0001:0000:0000:0101	3194::/64

Table K-6. Answers: Finding the IPv6 Prefix, with Other Prefix Lengths

	Address	Prefix (Subnet)
1	2987:BA11:B011:B00A:1000:0001:F001:F003 /60	2987:BA11:B011:B000::/60
2	3100:0000:0000:1010:D00D:D000:D00B:B00D /56	3100:0:0:1000::/56
3	FD00:0001:0001:0001:0200:00FF:FE00:0001 /52	FD00:1:1::/52
4	FDDF:8080:0880:1001:0000:00FF:FE01:0507 /48	FDDF:8080:880::/48
5	32CC:0000:0000:000D:210F:0000:0000:0000 /44	32CC:::/44
6	2100:000E:00E0:0000:0000:0000:0000:0E00 /60	2100:E:E0::/60
7	3A11:CA00:0000:0000:0000:00FF:FECC:000C /56	3A11:CA00::/56
8	3799:9F9F:F000:0000:FFFF:0000:0000:0001 /52	3799:9F9F:F000::/52
9	2A2A:0000:0000:0000:0000:0000:0000:2A2A /48	2A2A::/48
10	3194:0000:0000:0000:0001:0000:0000:0101 /44	3194::/44

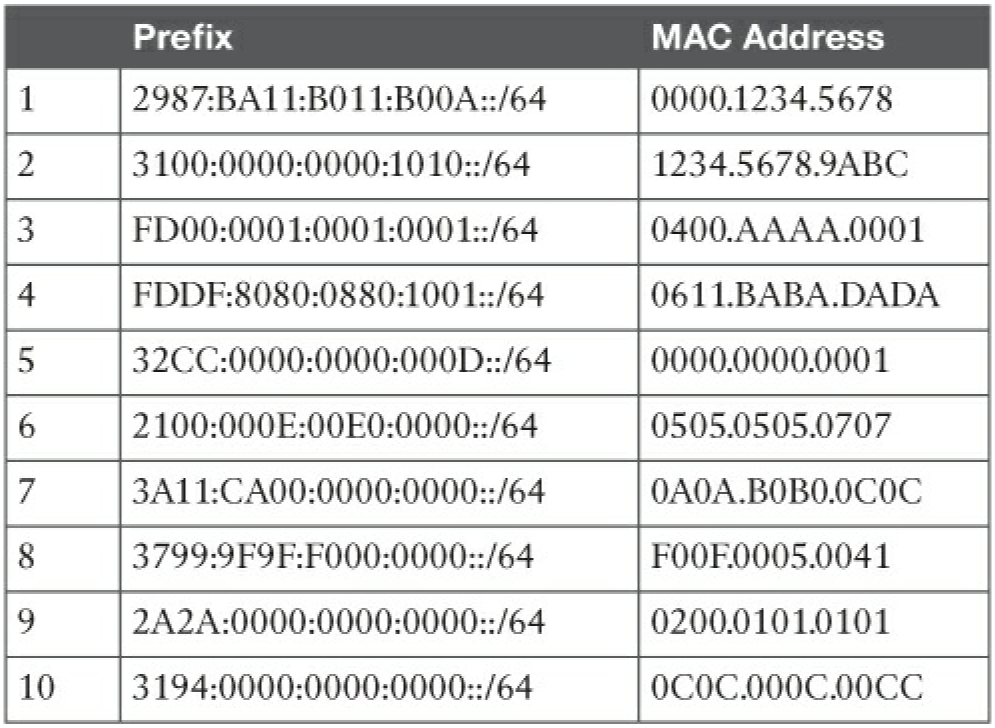
Appendix L. Practice for Chapter 27: Implementing IPv6 Addressing on Routers

This appendix provides practice problems for two types of addresses: unicast addresses formed with the EUI-64 feature and solicited node multicast addresses. With EUI-64, you take the 64-bit (16 hex digit) prefix and a MAC address, manipulate the MAC address into a 64-bit value, and use those 64 bits as the interface ID. Solicited node multicast addresses are formed from a standard 26 hex digit prefix, combined with the same last 6 hex digits as the unicast address.

EUI-64 and Solicited Node Multicast Problems

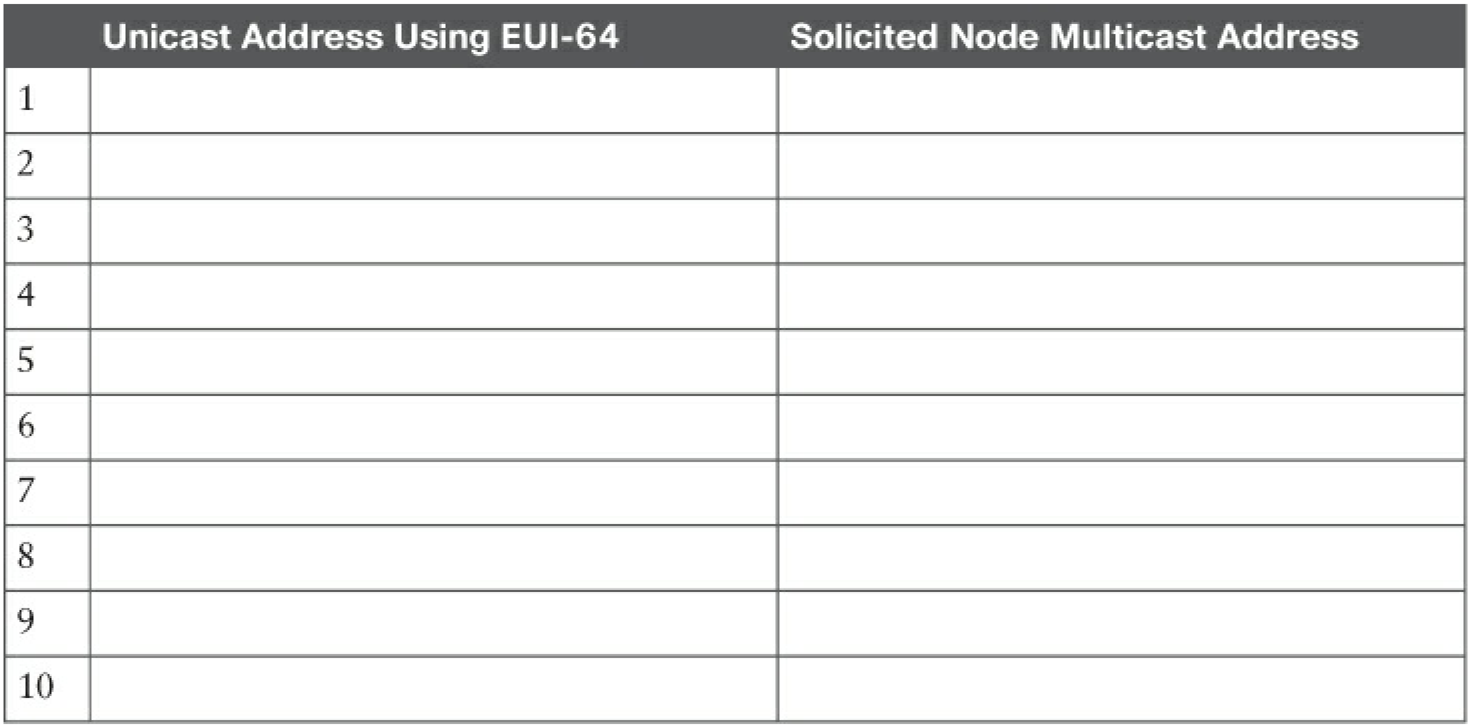
Table L-1 lists some practice problems. Each problem lists a prefix and a MAC address. Then, in Table L-2, record your answers for the unicast IPv6 address, assuming that EUI-64 rules are used. Also in Table L-2, list the solicited node multicast address associated with your calculated unicast address.

Table L-1. IPv6 EUI-64 Unicast and Solicited Node Multicast Problems



	Prefix	MAC Address
1	2987:BA11:B011:B00A::/64	0000.1234.5678
2	3100:0000:0000:1010::/64	1234.5678.9ABC
3	FD00:0001:0001:0001::/64	0400.AAAA.0001
4	FDDF:8080:0880:1001::/64	0611.BABA.DADA
5	32CC:0000:0000:000D::/64	0000.0000.0001
6	2100:000E:00E0:0000::/64	0505.0505.0707
7	3A11:CA00:0000:0000::/64	0A0A.B0B0.0C0C
8	3799:9F9F:F000:0000::/64	F00F.0005.0041
9	2A2A:0000:0000:0000::/64	0200.0101.0101
10	3194:0000:0000:0000::/64	0C0C.000C.00CC

Table L-2. Blank Answer Table for Problems in Table L-1

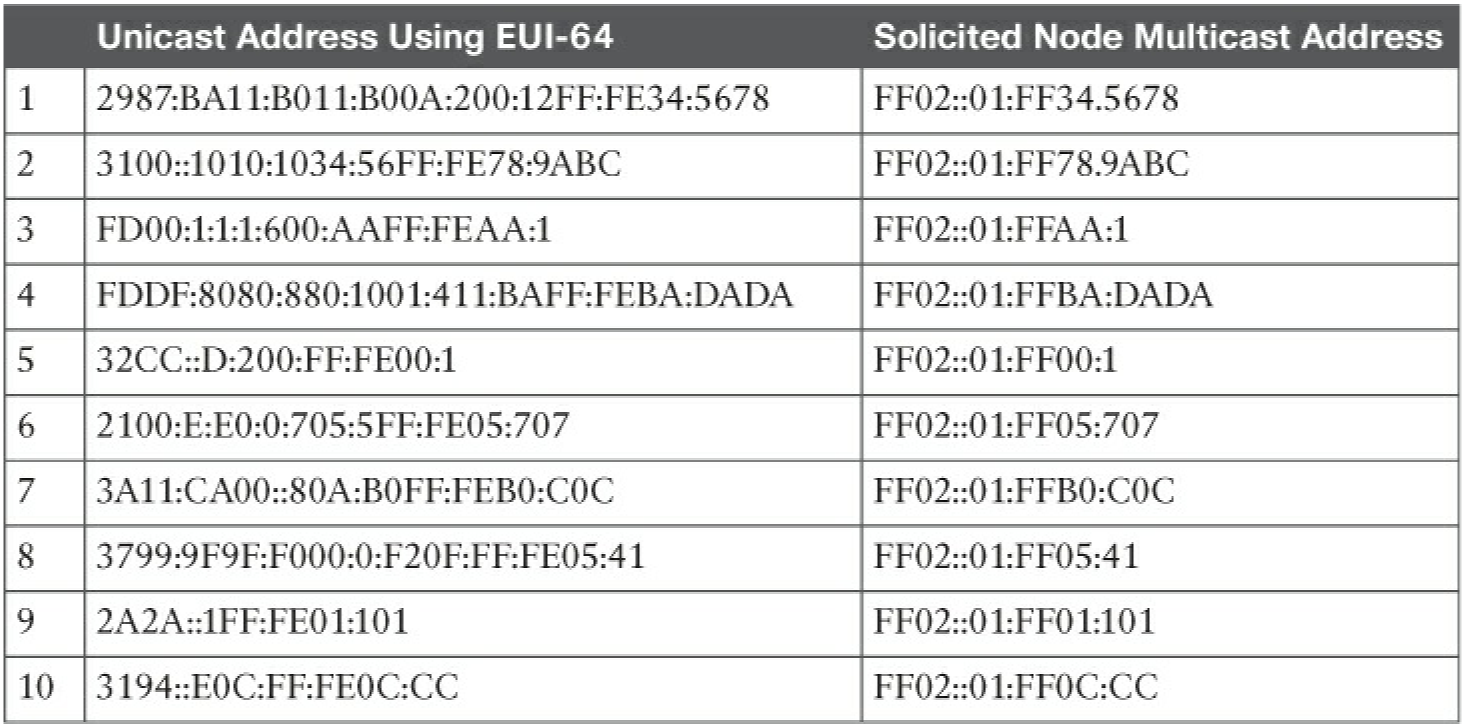


	Unicast Address Using EUI-64	Solicited Node Multicast Address
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

For each answer, use the best abbreviation, instead of a full 32-digit address.

The answers sit at the end of the appendix, in Table L-3.

Table L-3. Answers to Problems in Table L-1



	Unicast Address Using EUI-64	Solicited Node Multicast Address
1	2987:BA11:B011:B00A:200:12FF:FE34:5678	FF02::01:FF34.5678
2	3100::1010:1034:56FF:FE78:9ABC	FF02::01:FF78.9ABC
3	FD00:1:1:1:600:AAFF:FEAA:1	FF02::01:FFAA:1
4	FDDF:8080:880:1001:411:BAFF:FEBA:DADA	FF02::01:FFBA:DADA
5	32CC::D:200:FF:FE00:1	FF02::01:FF00:1
6	2100:E:E0:0:705:5FF:FE05:707	FF02::01:FF05:707
7	3A11:CA00::80A:B0FF:FEB0:C0C	FF02::01:FFB0:C0C
8	3799:9F9F:F000:0:F20F:FF:FE05:41	FF02::01:FF05:41
9	2A2A::1FF:FE01:101	FF02::01:FF01:101
10	3194::E0C:FF:FE0C:CC	FF02::01:FF0C:CC

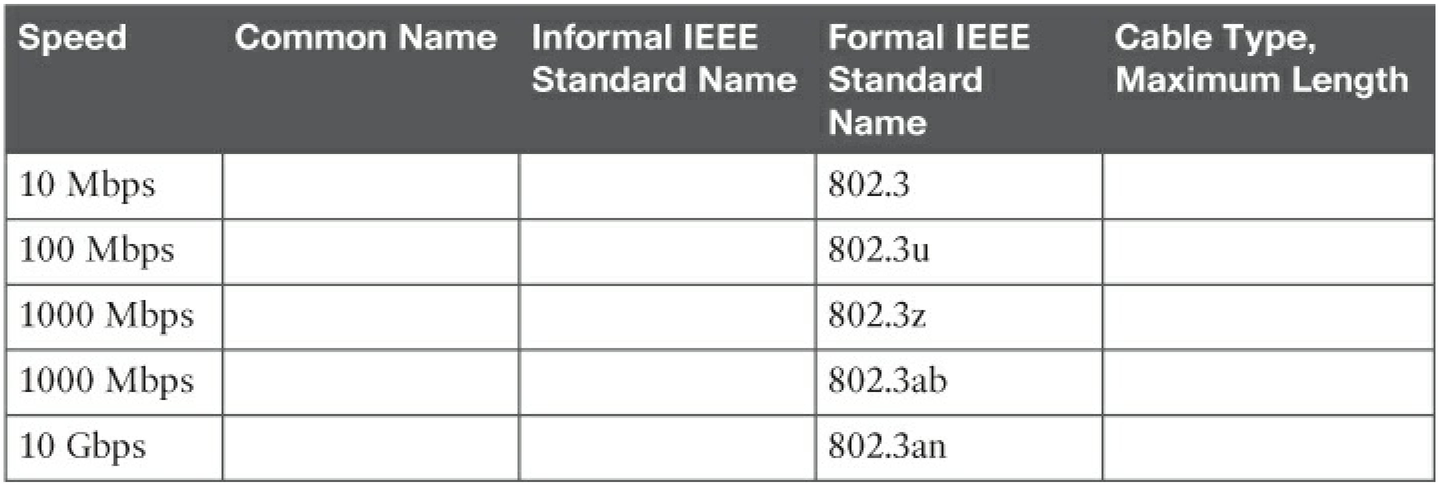
Answers to EUI-64 and Solicited Node Multicast Problems

Table L-3 lists the answers to the problems listed earlier in Table L-1.

Appendix M. Memory Tables

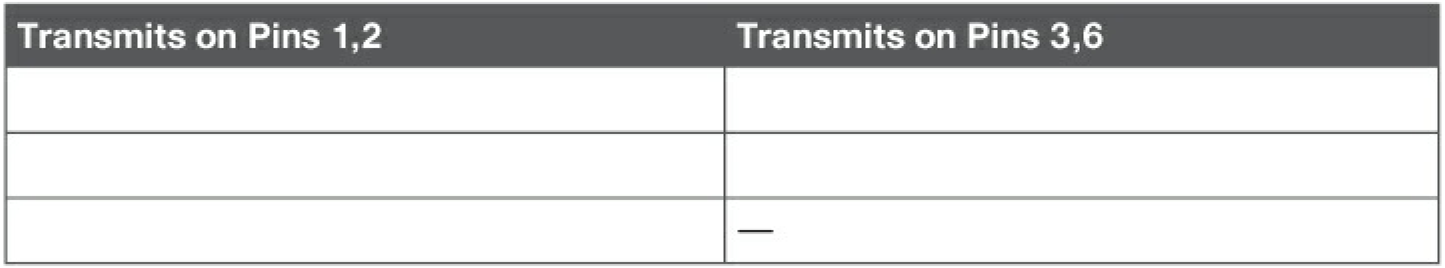
Chapter 2

Table 2-2. Examples of Types of Ethernet



Speed	Common Name	Informal IEEE Standard Name	Formal IEEE Standard Name	Cable Type, Maximum Length
10 Mbps			802.3	
100 Mbps			802.3u	
1000 Mbps			802.3z	
1000 Mbps			802.3ab	
10 Gbps			802.3an	

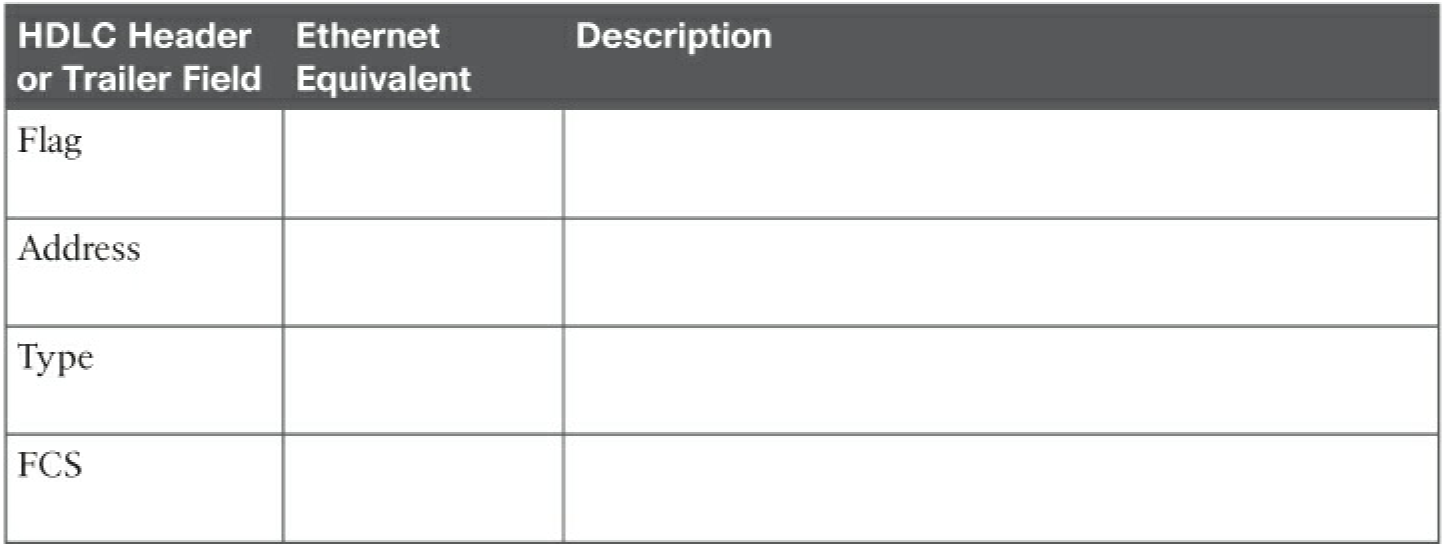
Table 2-3. 10BASE-T and 100BASE-TX Pin Pairs Used



Transmits on Pins 1,2	Transmits on Pins 3,6
	—

Chapter 3

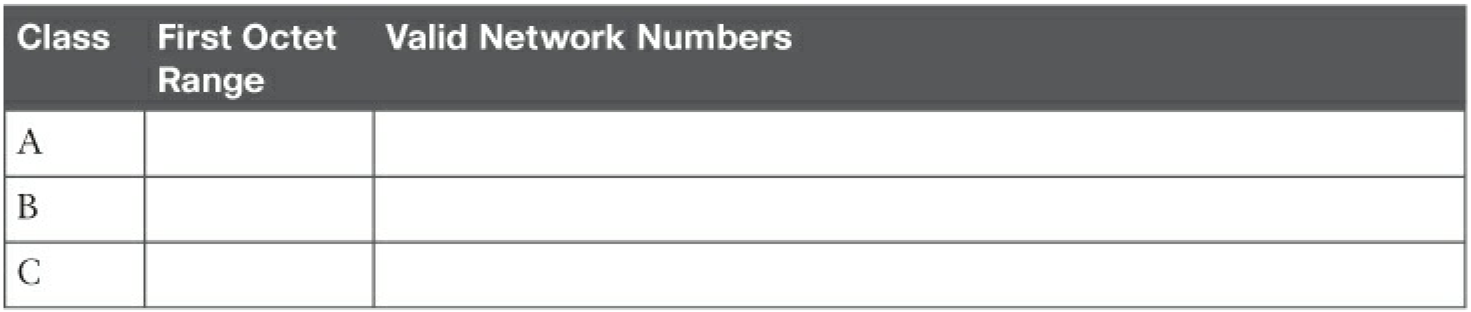
Table 3-3. Comparing HDLC Header Fields to Ethernet



HDLC Header or Trailer Field	Ethernet Equivalent	Description
Flag		
Address		
Type		
FCS		

Chapter 4

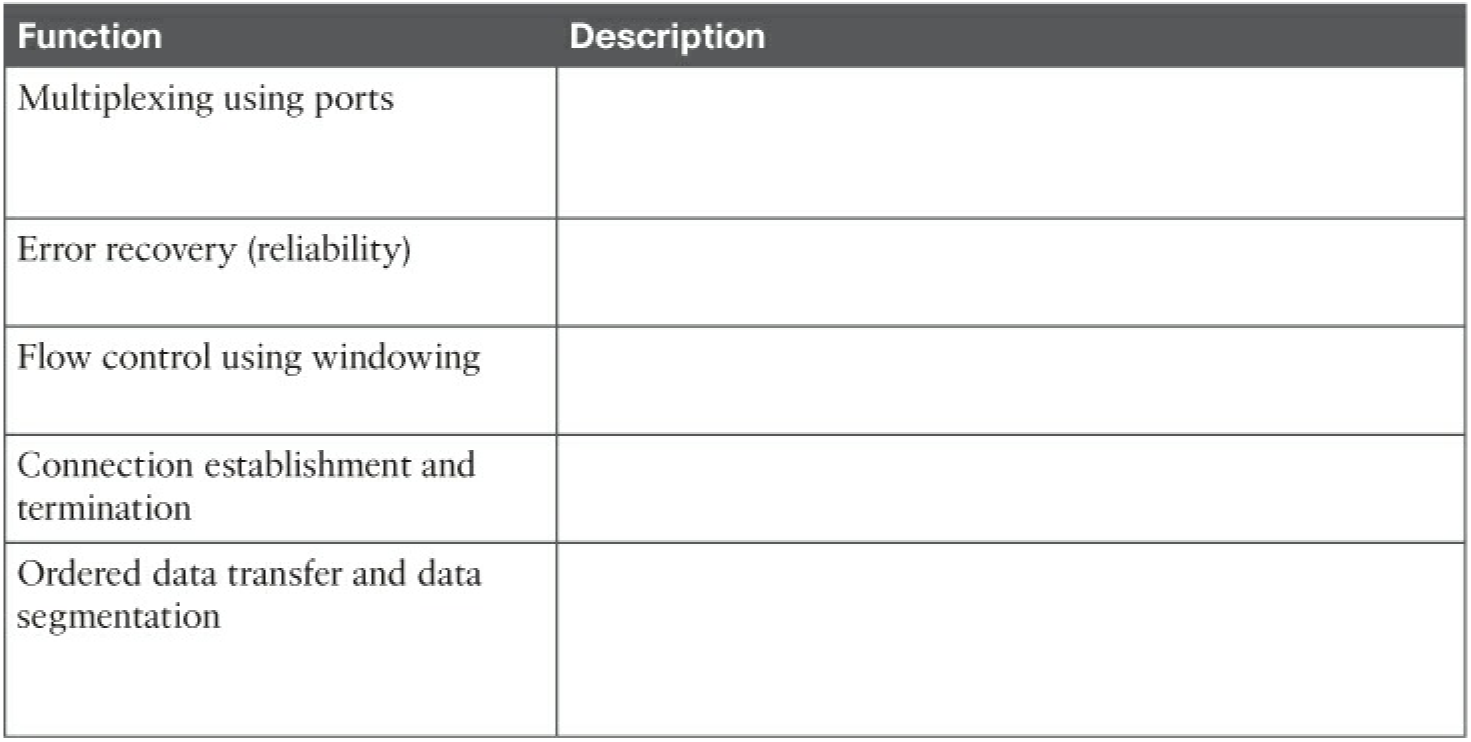
Table 4-6. All Possible Valid Network Numbers



Class	First Octet Range	Valid Network Numbers
A		
B		
C		

Chapter 5

Table 5-2. TCP/IP Transport Layer Features



Function	Description
Multiplexing using ports	
Error recovery (reliability)	
Flow control using windowing	
Connection establishment and termination	
Ordered data transfer and data segmentation	

Table 5-3. Popular Applications and Their Well-Known Port Numbers

Port Number	Protocol	Application
20	TCP	
21	TCP	
22	TCP	
23	TCP	
25	TCP	
53	UDP, TCP	
67, 68	UDP	
69	UDP	
80	TCP	
110	TCP	
161	UDP	
443	TCP	

Chapter 6

Table 6-2. Switch Internal Processing

Switching Method	Description
Store-and-forward	
Cut-through	
Fragment-free	

Table 6-3. Benefits of Segmenting Ethernet Devices Using Hubs, Switches, and Routers

Feature	Hub	Switch	Router
Greater cabling distances are allowed			
Creates multiple collision domains			
Increases bandwidth			
Creates multiple broadcast domains			

Chapter 7

Table 7-5. Key Sequences for Command Edit and Recall

Keyboard Command	What Happens
Up arrow or Ctrl-P	
Down arrow or Ctrl-N	
Left arrow or Ctrl-B	
Right arrow or Ctrl-F	
Backspace	
Ctrl-A	
Ctrl-E	
Ctrl-R	
Ctrl-D	
Ctrl-Shift-6	

Table 7-6. Common Switch Configuration Modes

Prompt	Name of Mode	Context-Setting Command(s) to Reach This Mode
hostname(config)#		
hostname(config-line)#		
hostname(config-if)#		
hostname(vlan)#		

Table 7-7. Names and Purposes of the Two Main Cisco IOS Configuration Files

Configuration Filename	Purpose	Where It Is Stored
Startup config		
Running config		

Chapter 8

Table 8-2. Banners and Their Use

Banner	Typical Use
Message of the Day (MOTD)	
Login	
Exec	

Table 8-3. Commands Related to the History Buffer

Command	Description
show history	
history size *x*	
terminal history size *x*	

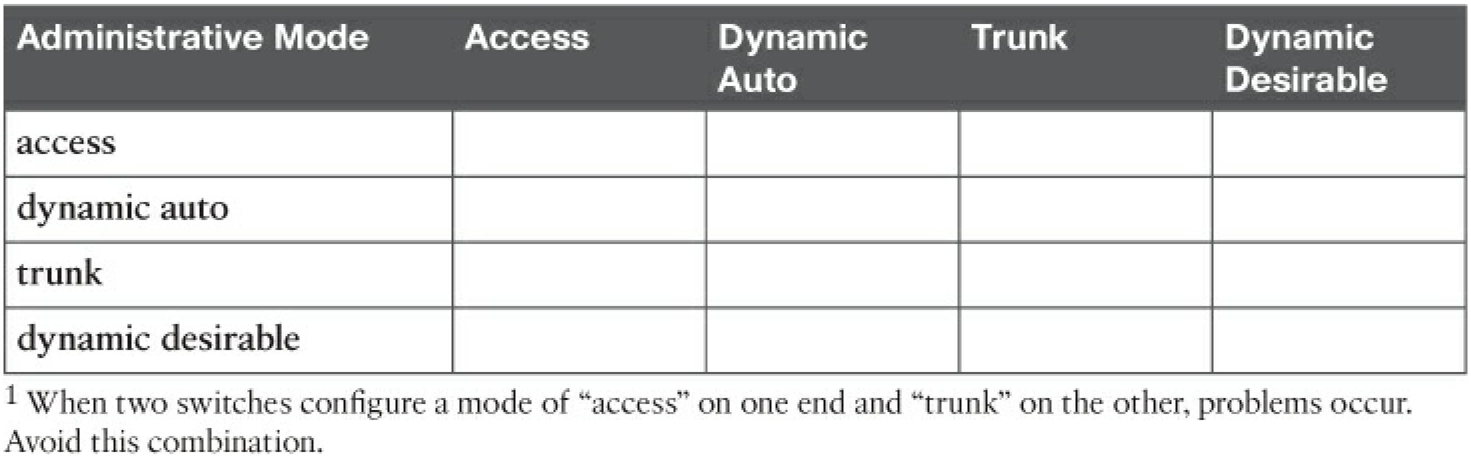
Table 8-4. Actions When Port Security Violation Occurs

Option on the switchport port-security violation Command	Protect	Restrict	Shutdown*
Discards offending traffic			
Sends log and SNMP messages			
Disables the interface, discarding all traffic			

* **shutdown** is the default setting.

Chapter 9

Table 9-3. Expected Trunking Operational Mode Based on the Configured Administrative Modes

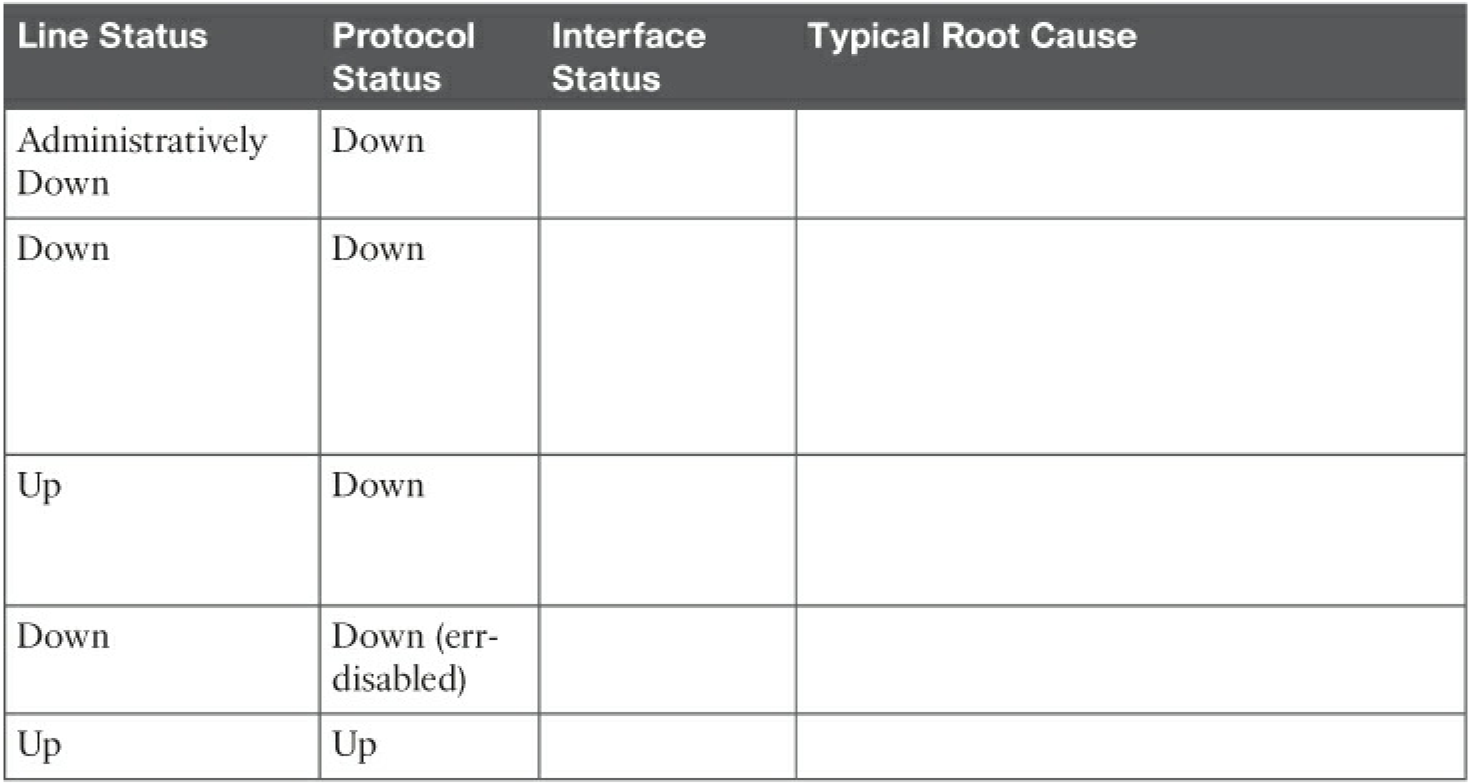


Administrative Mode	Access	Dynamic Auto	Trunk	Dynamic Desirable
access				
dynamic auto				
trunk				
dynamic desirable				

[1] When two switches configure a mode of "access" on one end and "trunk" on the other, problems occur. Avoid this combination.

Chapter 10

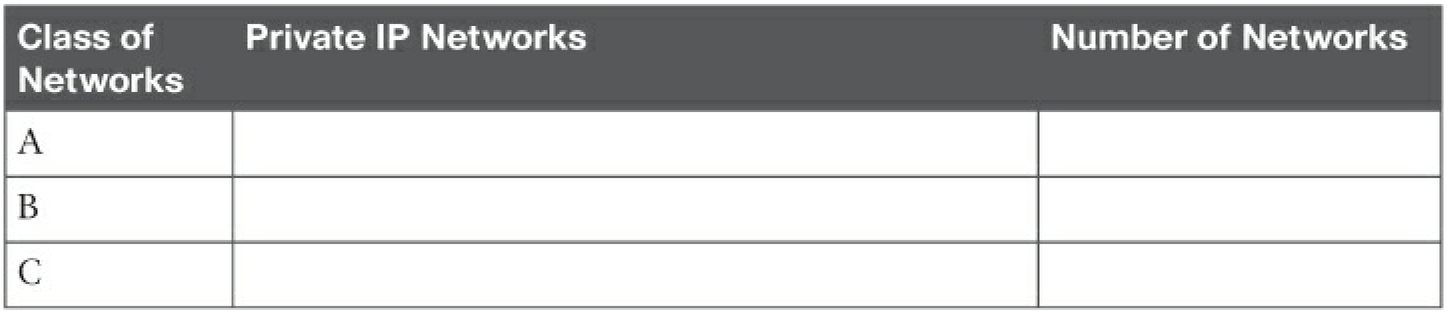
Table 10-4. LAN Switch Interface Status Codes



Line Status	Protocol Status	Interface Status	Typical Root Cause
Administratively Down	Down		
Down	Down		
Up	Down		
Down	Down (err-disabled)		
Up	Up		

Chapter 11

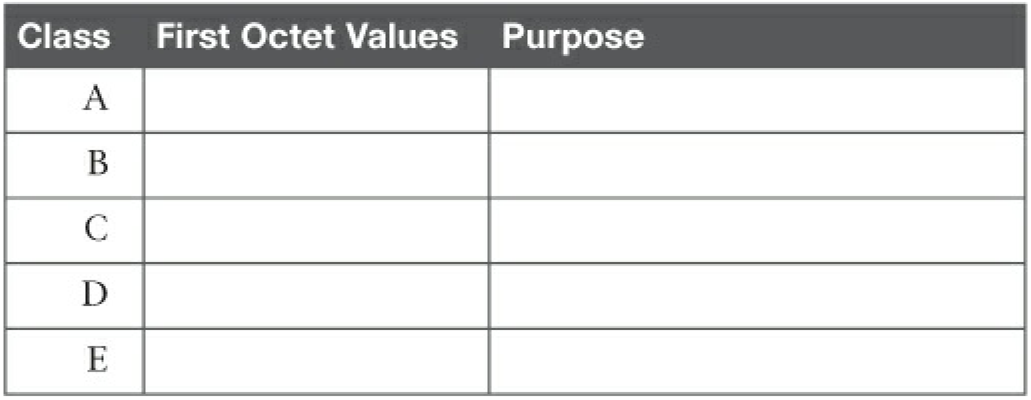
Table 11-2. RFC 1918 Private Address Space



Class of Networks	Private IP Networks	Number of Networks
A		
B		
C		

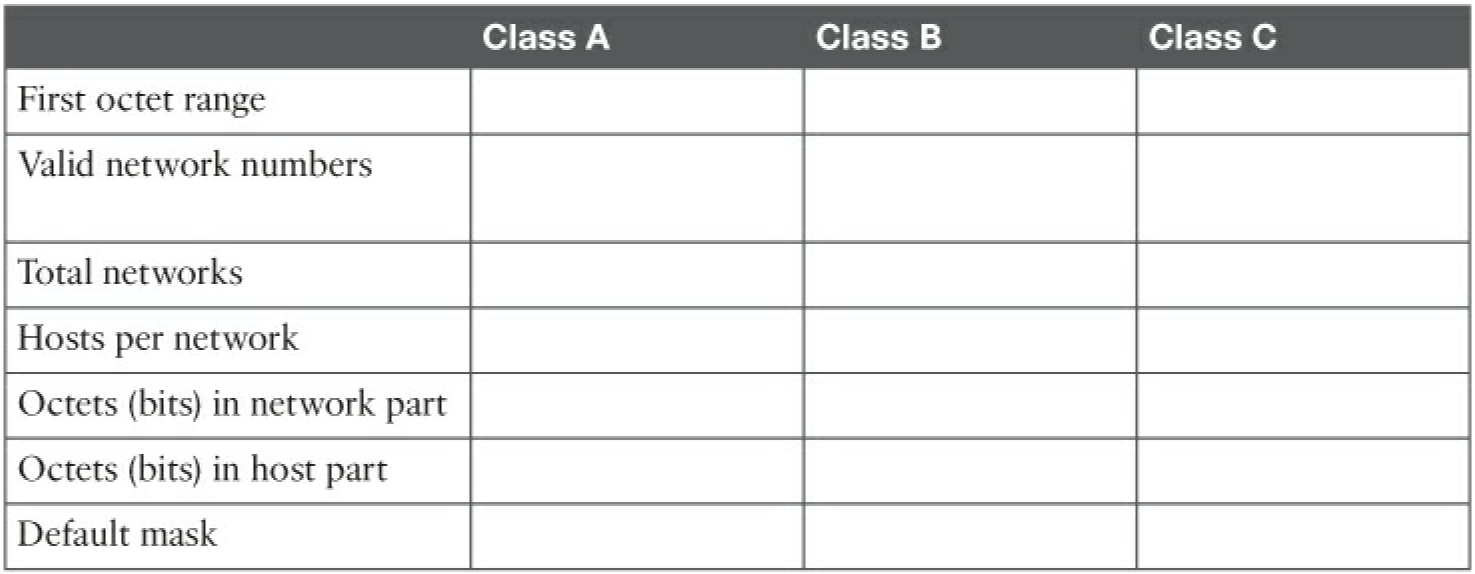
Chapter 12

Table 12-2. IPv4 Address Classes Based on First Octet Values



Class	First Octet Values	Purpose
A		
B		
C		
D		
E		

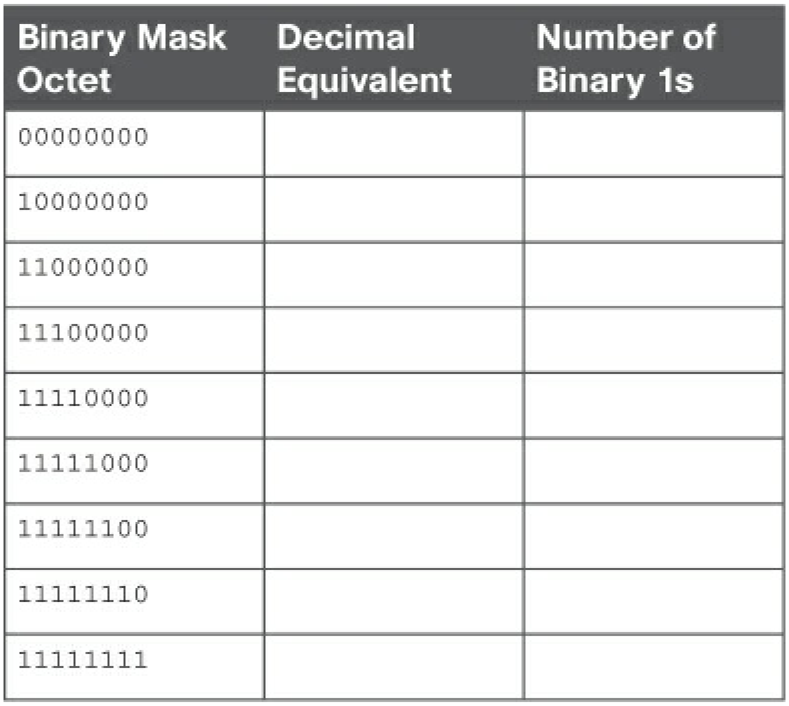
Table 12-3. Key Facts for Classes A, B, and C



	Class A	Class B	Class C
First octet range			
Valid network numbers			
Total networks			
Hosts per network			
Octets (bits) in network part			
Octets (bits) in host part			
Default mask			

Chapter 13

Table 13-4. Nine Possible Values in One Octet of a Subnet Mask



Binary Mask Octet	Decimal Equivalent	Number of Binary 1s
00000000		
10000000		
11000000		
11100000		
11110000		
11111000		
11111100		
11111110		
11111111		

Chapter 14

Table 14-2. Summary of Subnet ID Key Facts

Definition	
Numeric Value	
Literal Synonyms	
Common-Use Synonyms	
Typically Seen In...	

Chapter 15

Table 15-2. Interface Status Codes and Their Meanings

Name	Location	General Meaning
Line status		
Protocol status		

Table 15-4. Key Commands to List Router Interface Status

Command	Lines of Output per Interface	IP Configuration Listed	Interface Status Listed?
show ip interface brief			
show protocols [*type number*]			
show interfaces [*type number*]			

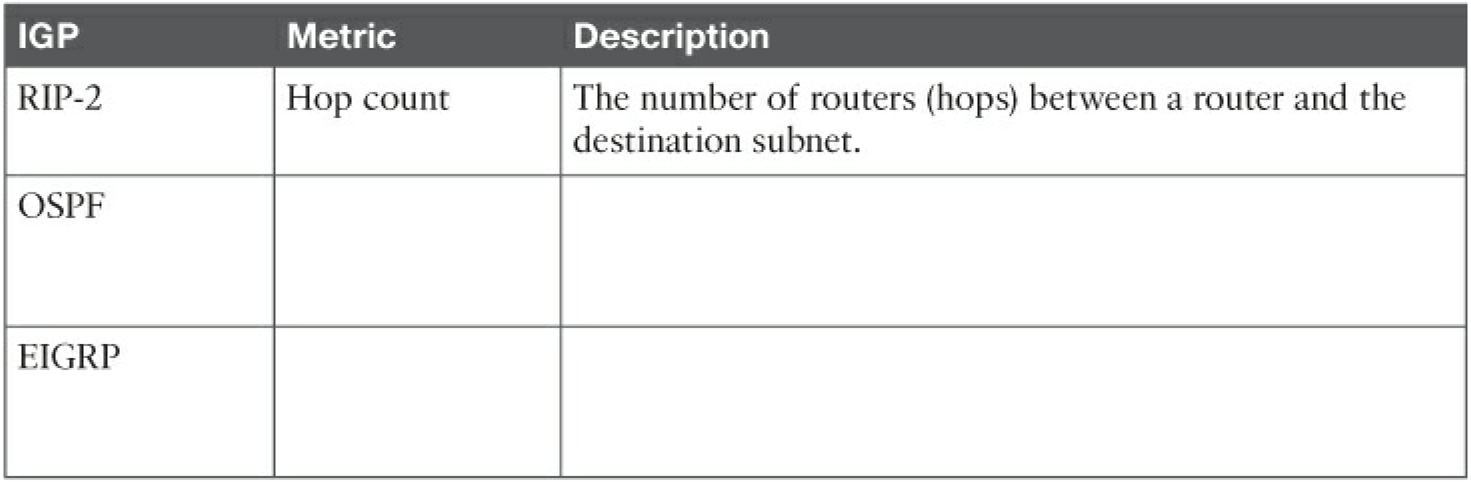
Chapter 16

Table 16-2. Comparisons of Packet Switching, Fast Switching, and CEF

Improves Routing Efficiency by...	Process Switching	Fast Switching	CEF
...saving data link headers used for encapsulating packets			
...using other tables, with faster lookup time, before looking at the routing table			
...organizing the tables using tree structures for very fast searches and less time to route packets			

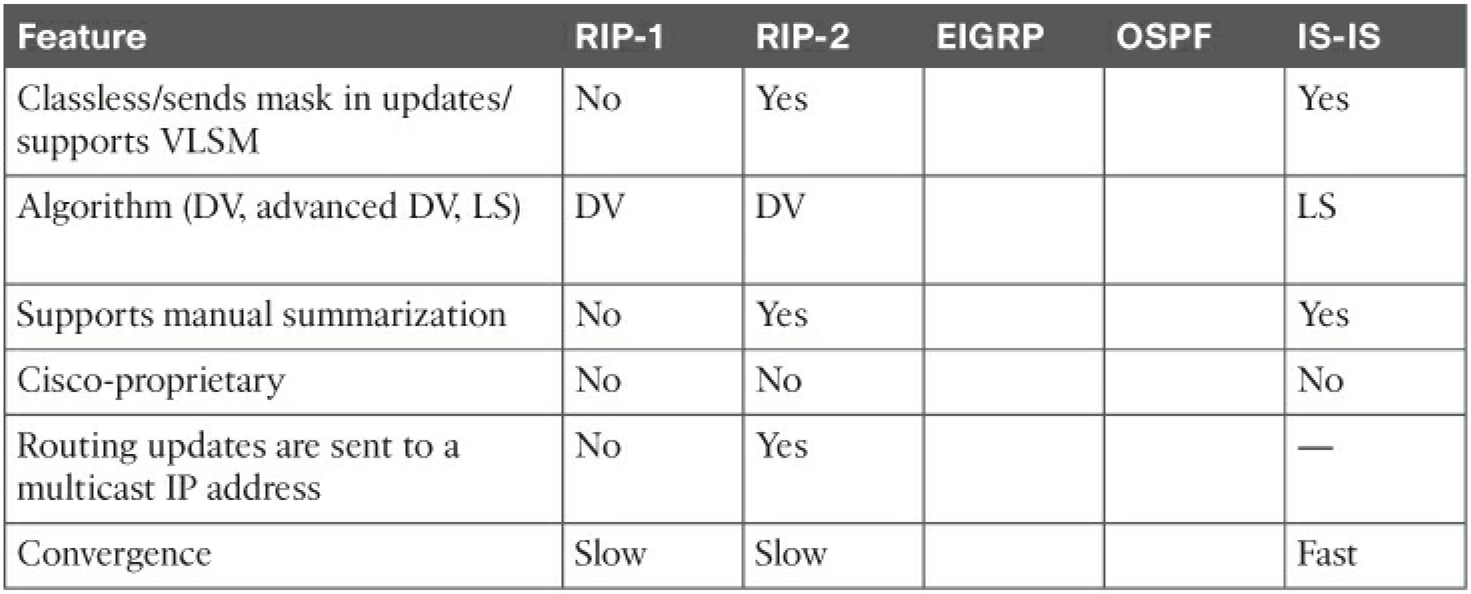
Chapter 17

Table 17-2. IP IGP Metrics



IGP	Metric	Description
RIP-2	Hop count	The number of routers (hops) between a router and the destination subnet.
OSPF		
EIGRP		

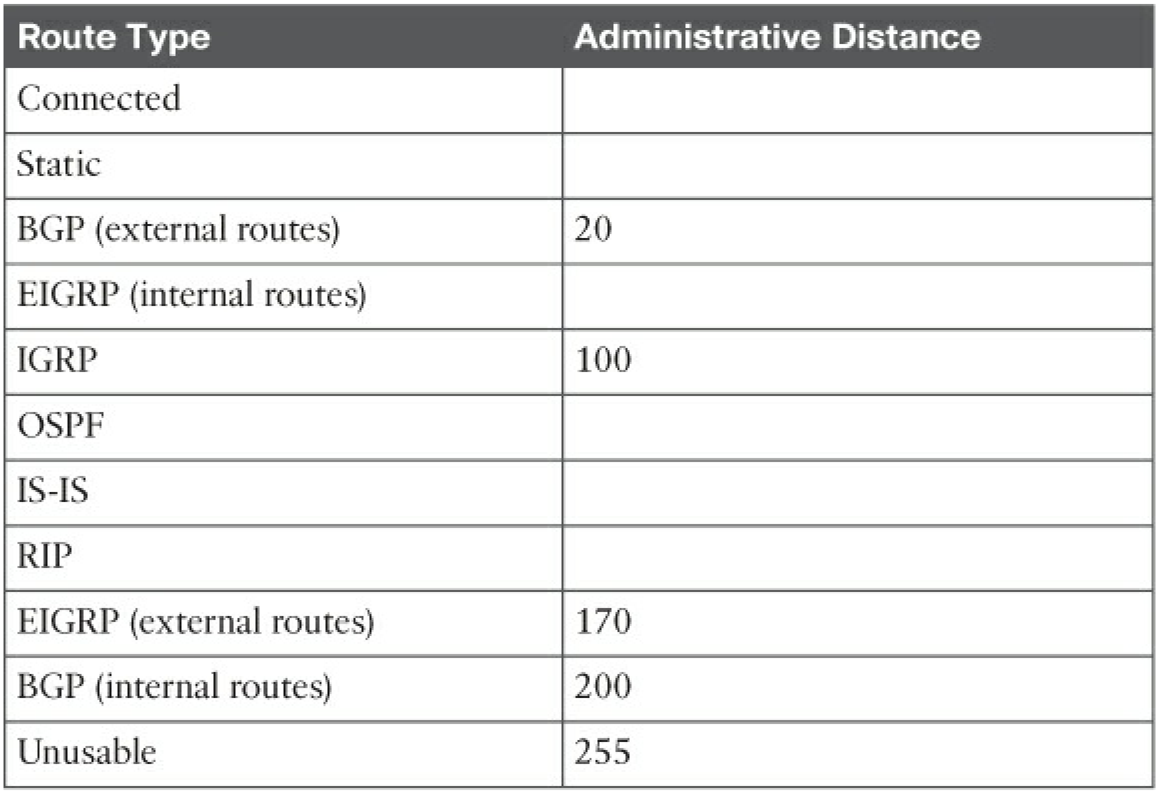
Table 17-3. Interior IP Routing Protocols Compared



Feature	RIP-1	RIP-2	EIGRP	OSPF	IS-IS
Classless/sends mask in updates/ supports VLSM	No	Yes			Yes
Algorithm (DV, advanced DV, LS)	DV	DV			LS
Supports manual summarization	No	Yes			Yes
Cisco-proprietary	No	No			No
Routing updates are sent to a multicast IP address	No	Yes			—
Convergence	Slow	Slow			Fast

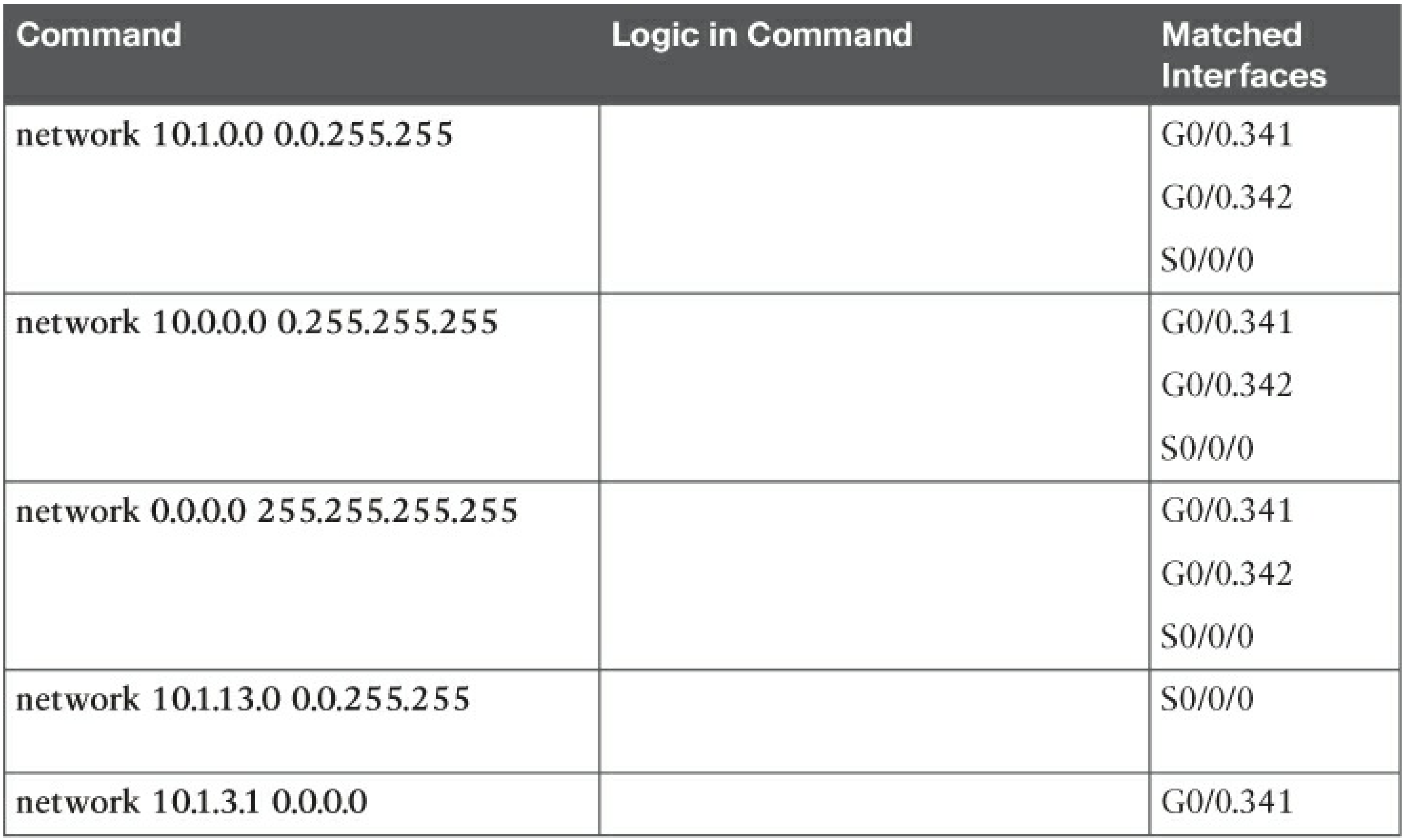
1 Although Cisco created EIGRP, and has kept it as a proprietary protocol for many years, Cisco happened to choose to publish EIGRP as an informational RFC around the time this book was published in early 2013. This choice allows other vendors to implement EIGRP, while Cisco retains the rights to the protocol.

Table 17-4. Default Administrative Distances



Route Type	Administrative Distance
Connected	
Static	
BGP (external routes)	20
EIGRP (internal routes)	
IGRP	100
OSPF	
IS-IS	
RIP	
EIGRP (external routes)	170
BGP (internal routes)	200
Unusable	255

Table 17-5. Example OSPF network **Commands on R3, with Expected Results**



Command	Logic in Command	Matched Interfaces
network 10.1.0.0 0.0.255.255		G0/0.341 G0/0.342 S0/0/0
network 10.0.0.0 0.255.255.255		G0/0.341 G0/0.342 S0/0/0
network 0.0.0.0 255.255.255.255		G0/0.341 G0/0.342 S0/0/0
network 10.1.13.0 0.0.255.255		S0/0/0
network 10.1.3.1 0.0.0.0		G0/0.341

Chapter 20

Table 20-2. Classless and Classful Interior IP Routing Protocols

Routing Protocol	Is It Classless?	Sends Mask in Updates?	Supports VLSM?	Supports Manual Route Summarization?
RIP-1				
IGRP				
RIP-2				
EIGRP				
OSPF				

Chapter 24

Table 24-2. RFC 1918 Private Address Space

Range of IP Addresses	Class of Networks	Number of Networks
10.0.0.0 to 10.255.255.255		
172.16.0.0 to 172.31.255.255		
192.168.0.0 to 192.168.255.255		

Chapter 25

Table 25-3. Hexadecimal/Binary Conversion Chart

Hex	Binary	Hex	Binary
0		8	
1		9	
2		A	
3		B	
4		C	
5		D	
6		E	
7		F	

Chapter 26

Table 26-2. Some Types of IPv6 Addresses and Their First Hex Digit(s)

Address Type	First Hex Digits
Global Unicast	
Unique Local	
Multicast	
Link-Local	

Chapter 27

Table 27-3. Key IPv6 Local-Scope Multicast Addresses

Short Name	Multicast Address	Meaning	IPv4 Equivalent
All-nodes			
All-routers			
All-OSPF, All-OSPF-DR			
EIGRPv6 Routers			

Chapter 28

Table 28-2. NDP Function Summary

Function	Protocol Messages	Who Discovers Info	Who Supplies Info	Info Supplied
Router discovery				
Prefix/length discovery				
Neighbor discovery				
Duplicate Address Detection				

Table 28-3. Comparison of Stateless and Stateful DHCPv6 Services

Feature	Stateful DHCP	Stateless DHCP
Remembers IPv6 address (state information) of clients that make requests		
Leases IPv6 address to client		
Supplies list of DNS server addresses		
Commonly used with SLAAC		

Chapter 29

Table 29-2. Summary of Version Terminology for Interior Routing Protocols

	RIP	OSPF	EIGRP
Latest version that supports IPv4 routes			
Version that supports IPv6 routes			

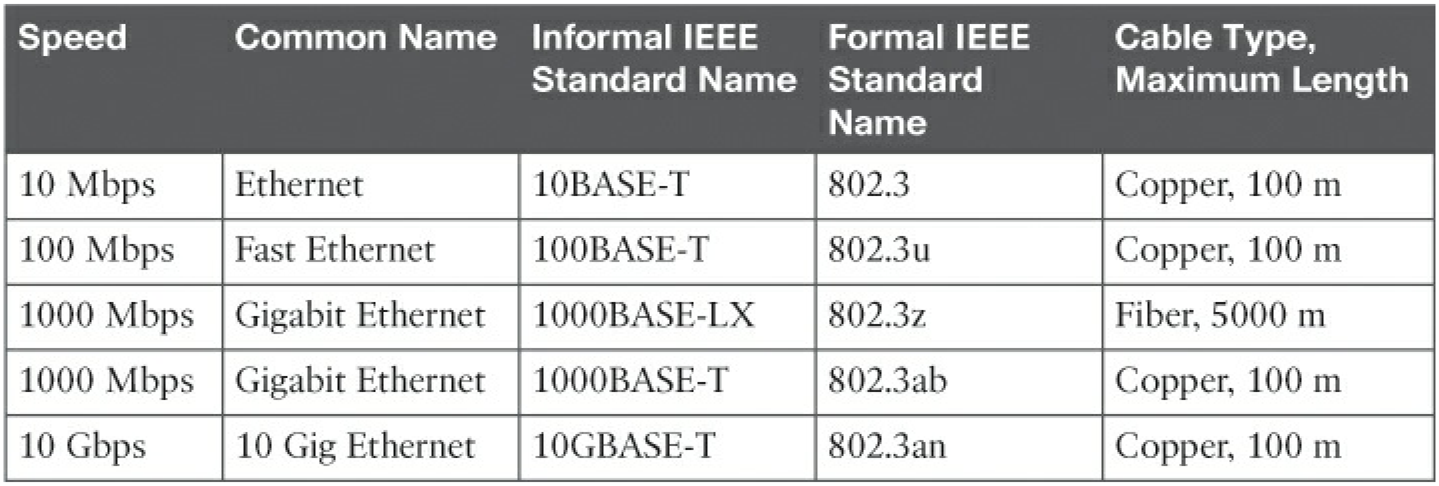
Table 29-3. OSPFv2 and Matching OSPFv3 show **Commands**

To Display Details About...	OSPFv2	OSPFv3
OSPF process		
All sources of routing information		
Details about OSPF-enabled interfaces		
Concise info about OSPF-enabled interfaces		
List of neighbors		
Summary of LSDB		
OSPF-learned routes		

Appendix N. Memory Tables Answer Key

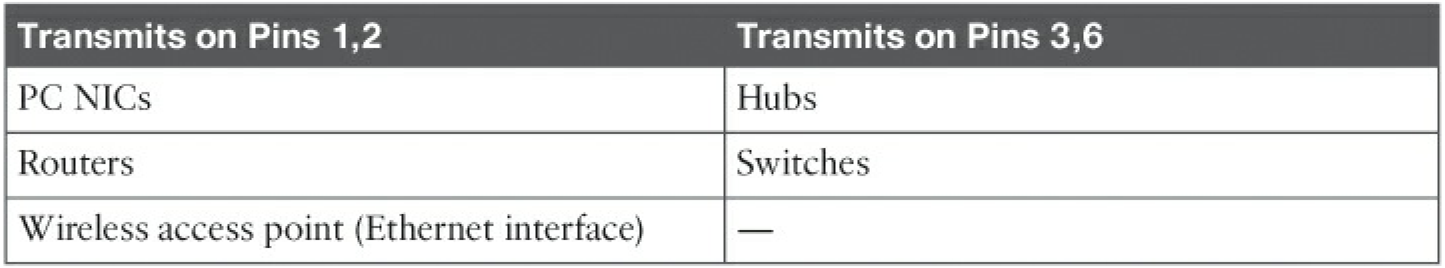
Chapter 2

Table 2-2. Examples of Types of Ethernet



Speed	Common Name	Informal IEEE Standard Name	Formal IEEE Standard Name	Cable Type, Maximum Length
10 Mbps	Ethernet	10BASE-T	802.3	Copper, 100 m
100 Mbps	Fast Ethernet	100BASE-T	802.3u	Copper, 100 m
1000 Mbps	Gigabit Ethernet	1000BASE-LX	802.3z	Fiber, 5000 m
1000 Mbps	Gigabit Ethernet	1000BASE-T	802.3ab	Copper, 100 m
10 Gbps	10 Gig Ethernet	10GBASE-T	802.3an	Copper, 100 m

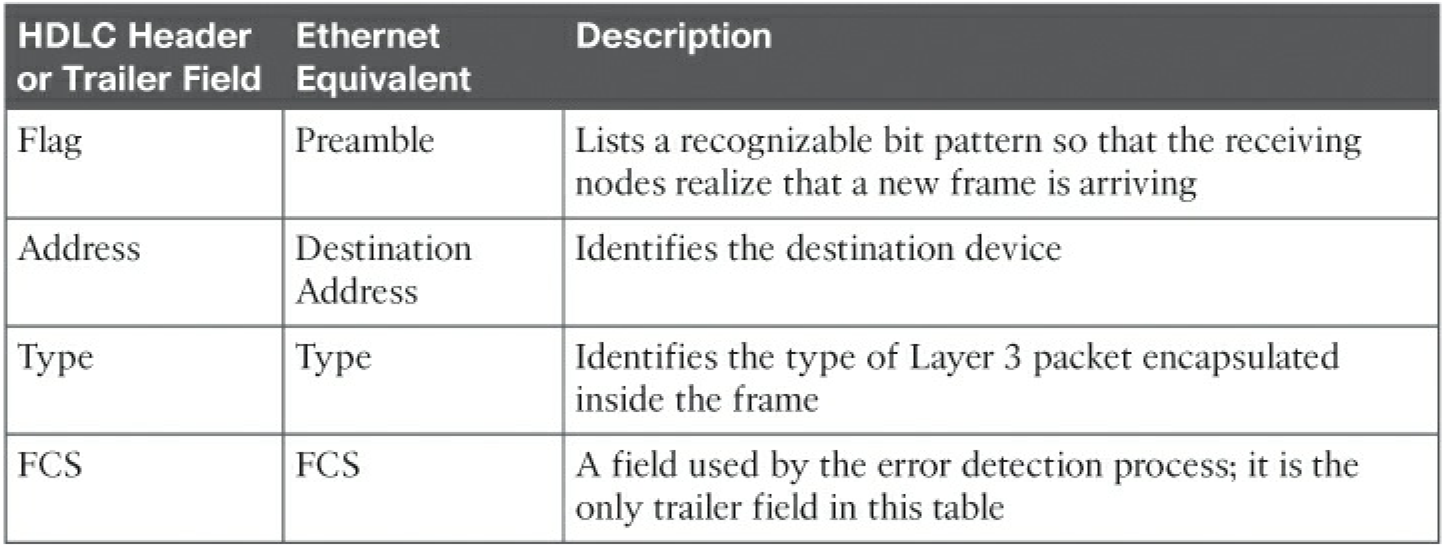
Table 2-3. 10BASE-T and 100BASE-TX Pin Pairs Used



Transmits on Pins 1,2	Transmits on Pins 3,6
PC NICs	Hubs
Routers	Switches
Wireless access point (Ethernet interface)	—

Chapter 3

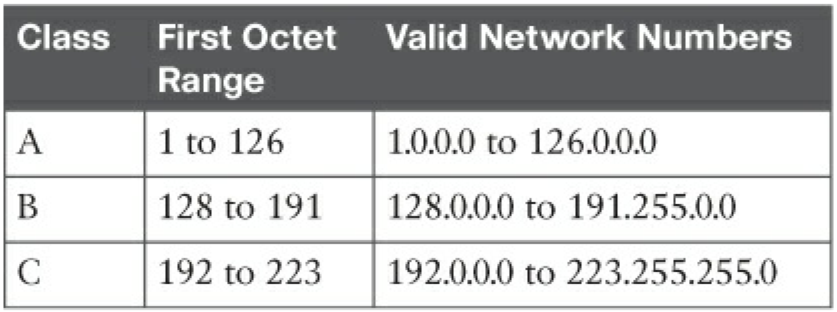
Table 3-3. Comparing HDLC Header Fields to Ethernet



HDLC Header or Trailer Field	Ethernet Equivalent	Description
Flag	Preamble	Lists a recognizable bit pattern so that the receiving nodes realize that a new frame is arriving
Address	Destination Address	Identifies the destination device
Type	Type	Identifies the type of Layer 3 packet encapsulated inside the frame
FCS	FCS	A field used by the error detection process; it is the only trailer field in this table

Chapter 4

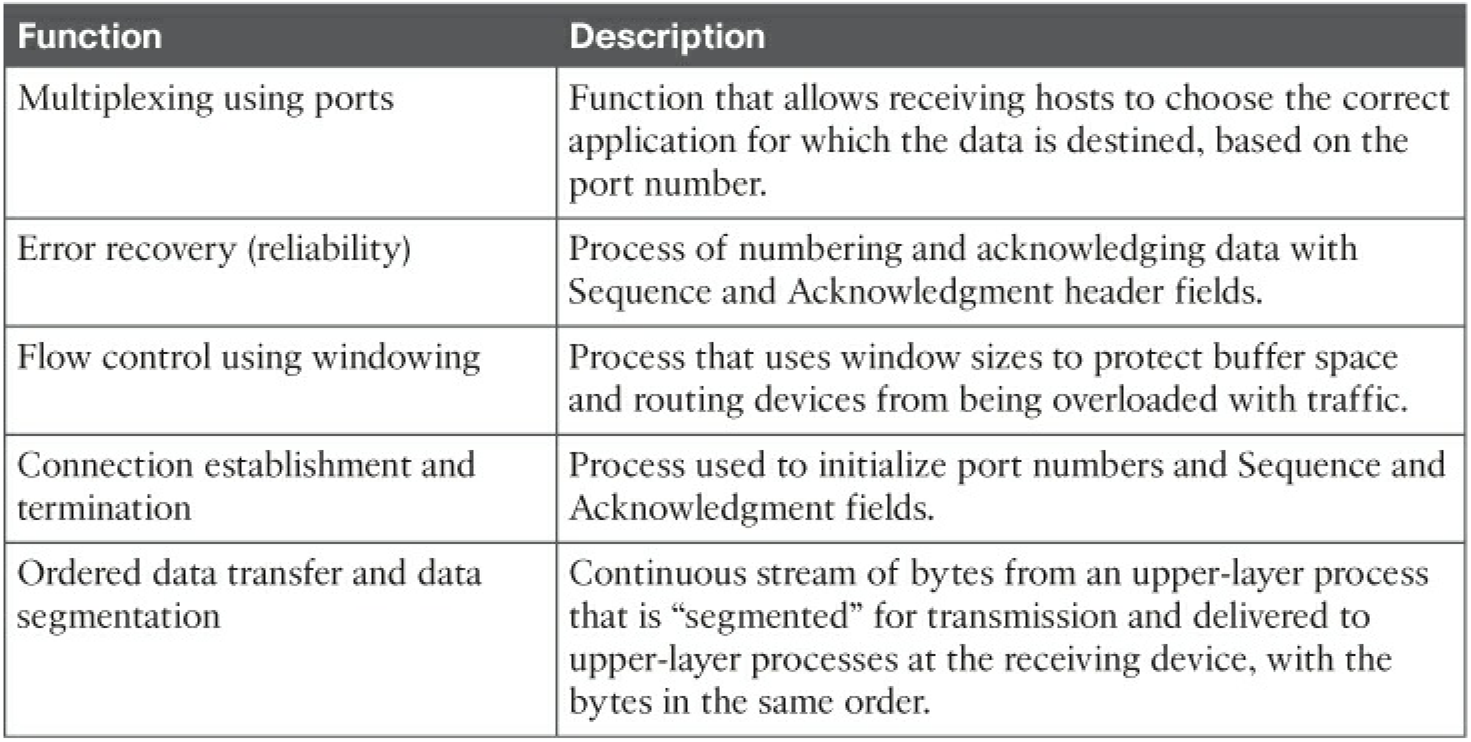
Table 4-6. All Possible Valid Network Numbers



Class	First Octet Range	Valid Network Numbers
A	1 to 126	1.0.0.0 to 126.0.0.0
B	128 to 191	128.0.0.0 to 191.255.0.0
C	192 to 223	192.0.0.0 to 223.255.255.0

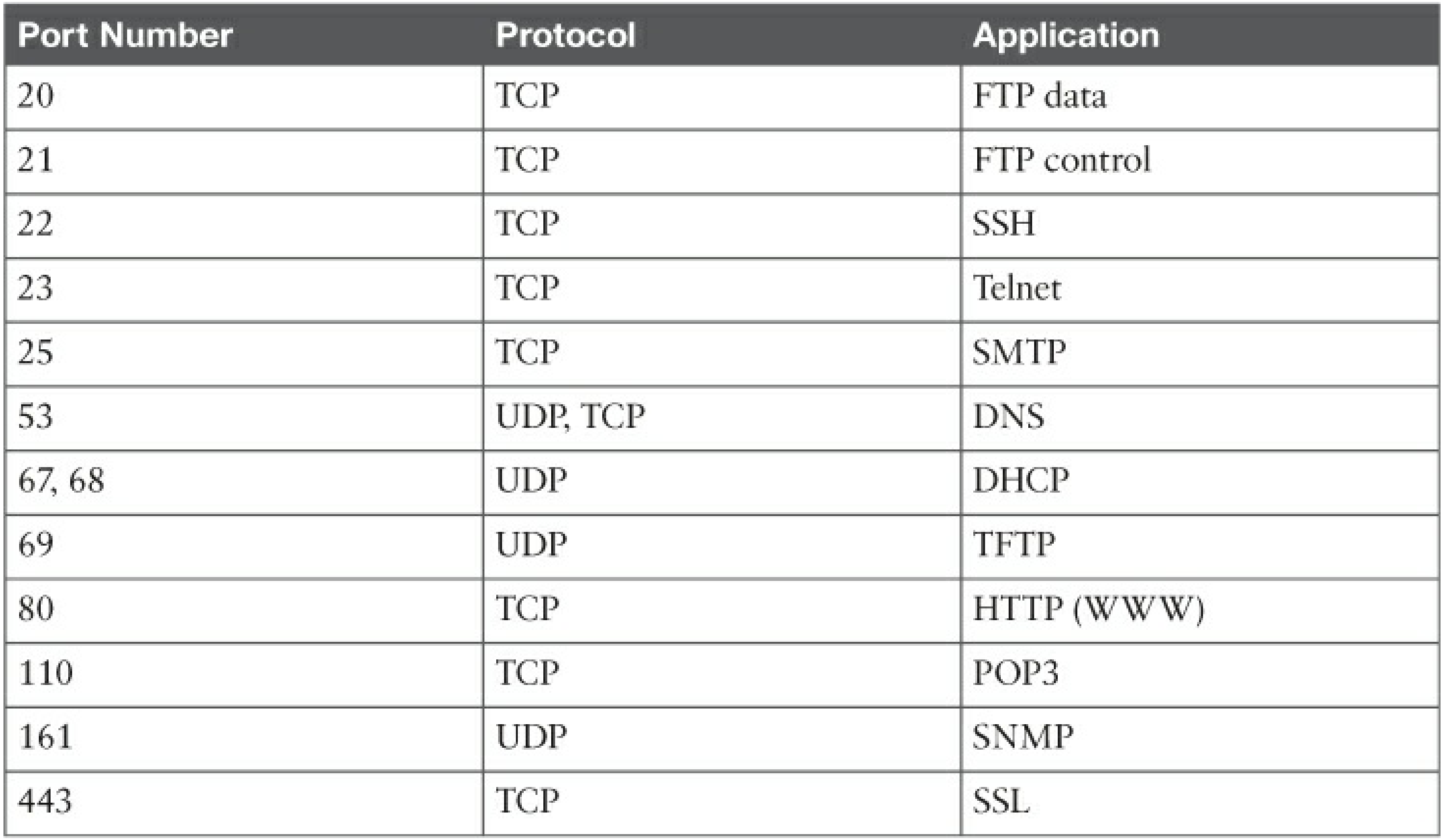
Chapter 5

Table 5-2. TCP/IP Transport Layer Features



Function	Description
Multiplexing using ports	Function that allows receiving hosts to choose the correct application for which the data is destined, based on the port number.
Error recovery (reliability)	Process of numbering and acknowledging data with Sequence and Acknowledgment header fields.
Flow control using windowing	Process that uses window sizes to protect buffer space and routing devices from being overloaded with traffic.
Connection establishment and termination	Process used to initialize port numbers and Sequence and Acknowledgment fields.
Ordered data transfer and data segmentation	Continuous stream of bytes from an upper-layer process that is "segmented" for transmission and delivered to upper-layer processes at the receiving device, with the bytes in the same order.

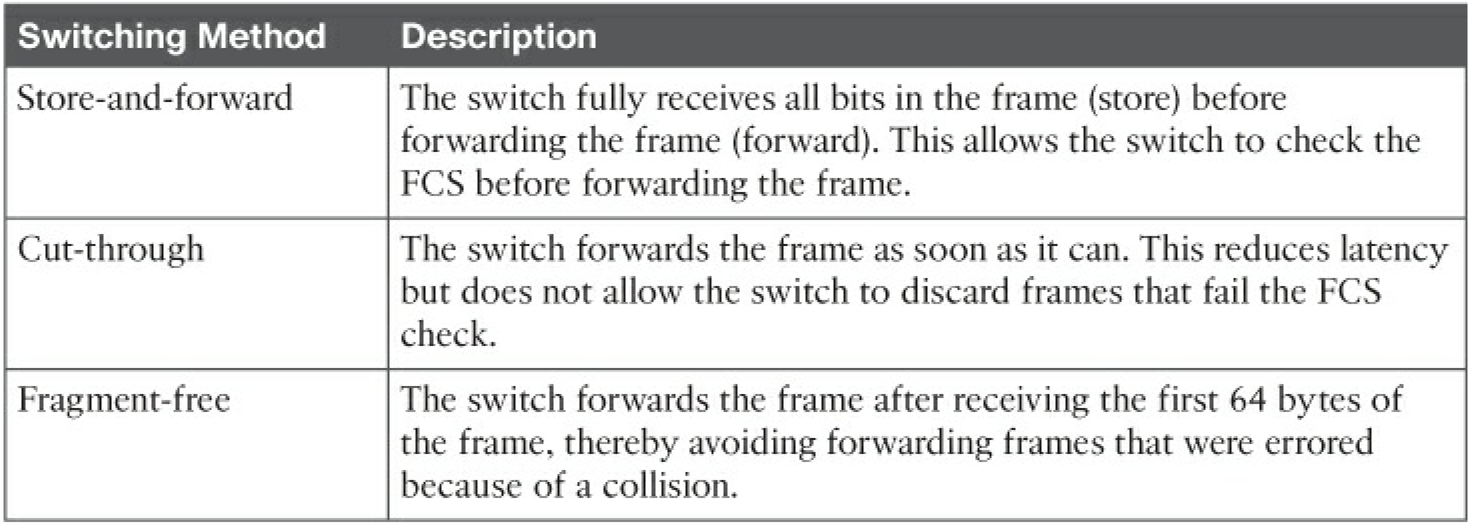
Table 5-3. Popular Applications and Their Well-Known Port Numbers



Port Number	Protocol	Application
20	TCP	FTP data
21	TCP	FTP control
22	TCP	SSH
23	TCP	Telnet
25	TCP	SMTP
53	UDP, TCP	DNS
67, 68	UDP	DHCP
69	UDP	TFTP
80	TCP	HTTP (WWW)
110	TCP	POP3
161	UDP	SNMP
443	TCP	SSL

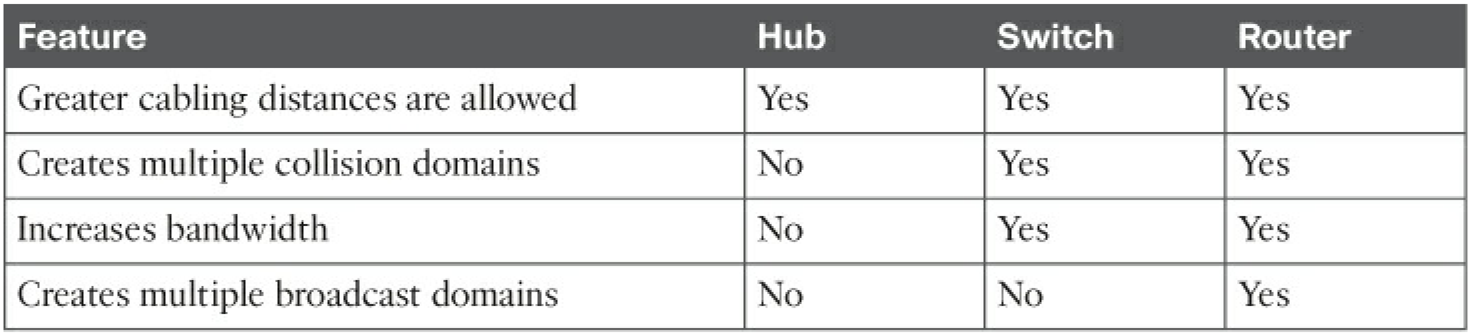
Chapter 6

Table 6-2. Switch Internal Processing



Switching Method	Description
Store-and-forward	The switch fully receives all bits in the frame (store) before forwarding the frame (forward). This allows the switch to check the FCS before forwarding the frame.
Cut-through	The switch forwards the frame as soon as it can. This reduces latency but does not allow the switch to discard frames that fail the FCS check.
Fragment-free	The switch forwards the frame after receiving the first 64 bytes of the frame, thereby avoiding forwarding frames that were errored because of a collision.

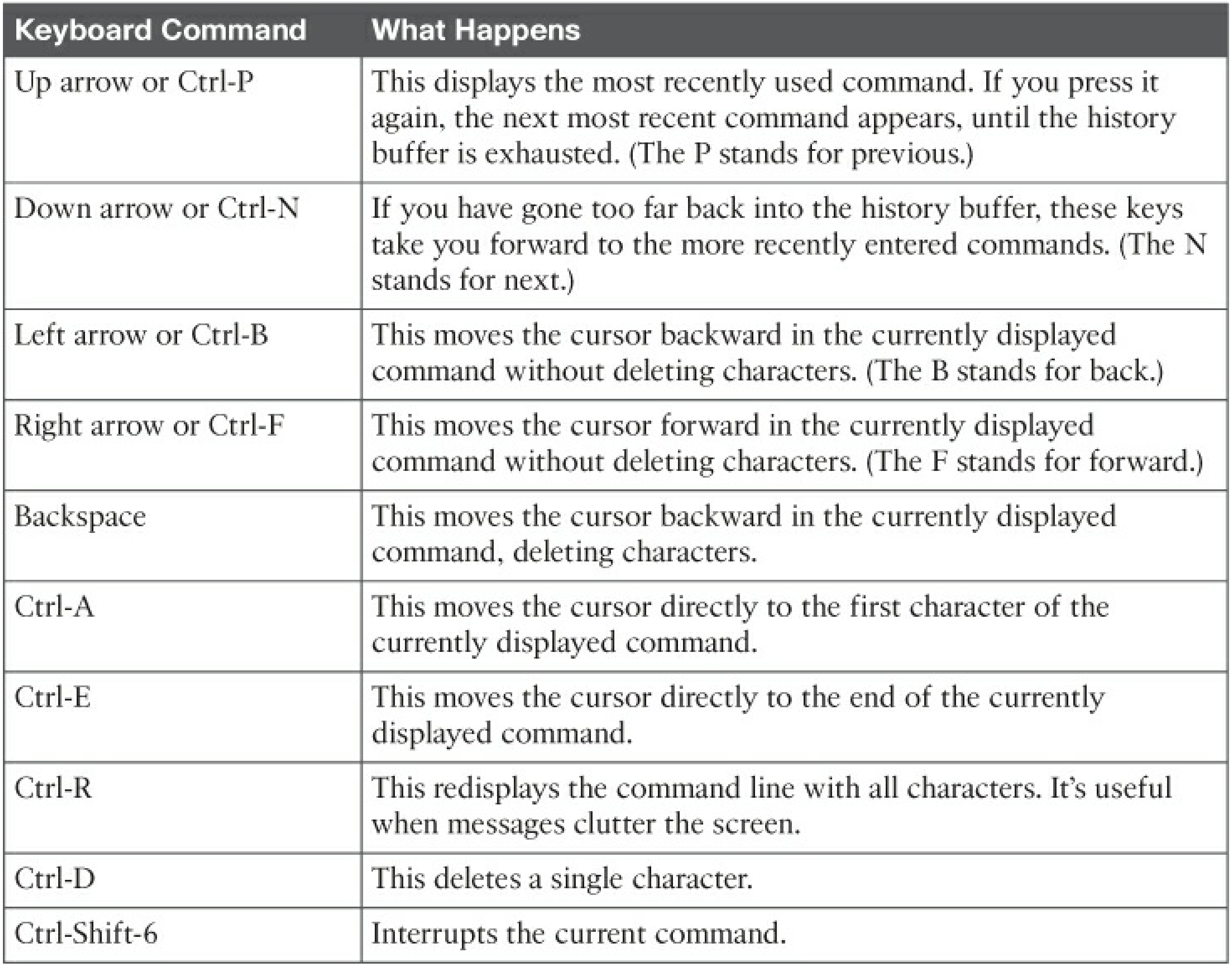
Table 6-3. Benefits of Segmenting Ethernet Devices Using Hubs, Switches, and Routers



Feature	Hub	Switch	Router
Greater cabling distances are allowed	Yes	Yes	Yes
Creates multiple collision domains	No	Yes	Yes
Increases bandwidth	No	Yes	Yes
Creates multiple broadcast domains	No	No	Yes

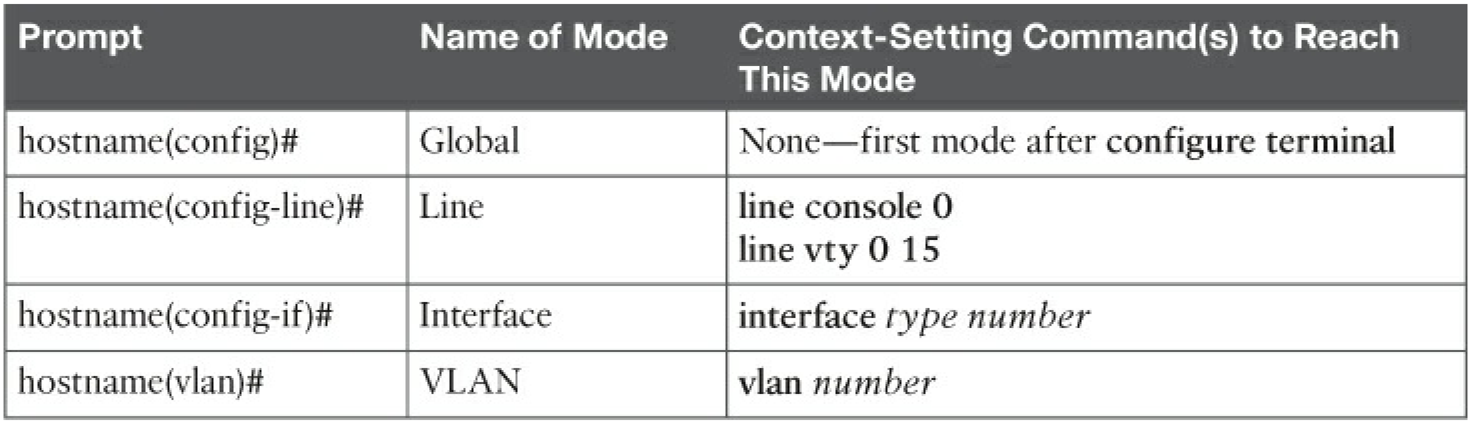
Chapter 7

Table 7-5. Key Sequences for Command Edit and Recall



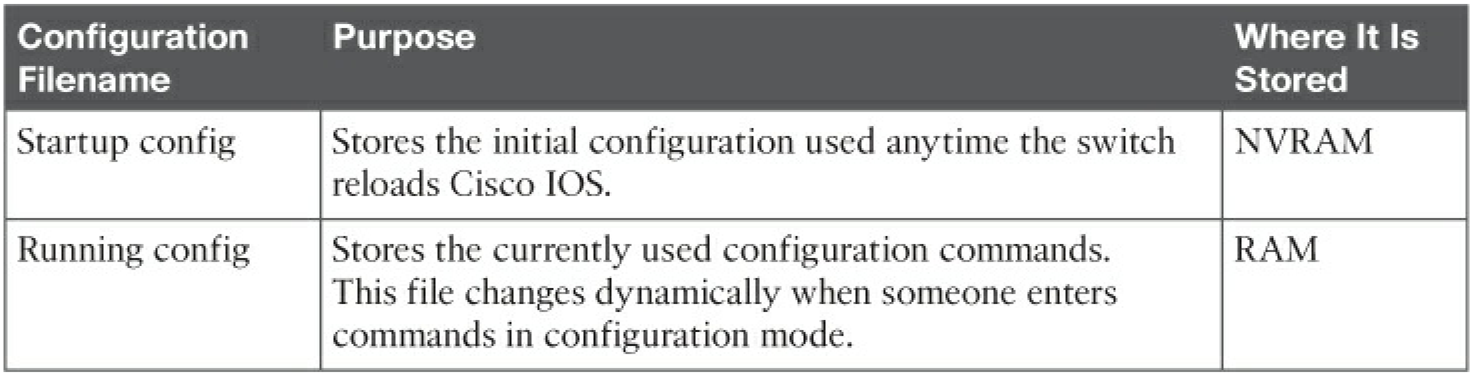
Keyboard Command	What Happens
Up arrow or Ctrl-P	This displays the most recently used command. If you press it again, the next most recent command appears, until the history buffer is exhausted. (The P stands for previous.)
Down arrow or Ctrl-N	If you have gone too far back into the history buffer, these keys take you forward to the more recently entered commands. (The N stands for next.)
Left arrow or Ctrl-B	This moves the cursor backward in the currently displayed command without deleting characters. (The B stands for back.)
Right arrow or Ctrl-F	This moves the cursor forward in the currently displayed command without deleting characters. (The F stands for forward.)
Backspace	This moves the cursor backward in the currently displayed command, deleting characters.
Ctrl-A	This moves the cursor directly to the first character of the currently displayed command.
Ctrl-E	This moves the cursor directly to the end of the currently displayed command.
Ctrl-R	This redisplays the command line with all characters. It's useful when messages clutter the screen.
Ctrl-D	This deletes a single character.
Ctrl-Shift-6	Interrupts the current command.

Table 7-6. Common Switch Configuration Modes



Prompt	Name of Mode	Context-Setting Command(s) to Reach This Mode
hostname(config)#	Global	None—first mode after **configure terminal**
hostname(config-line)#	Line	**line console 0** **line vty 0 15**
hostname(config-if)#	Interface	**interface** *type number*
hostname(vlan)#	VLAN	**vlan** *number*

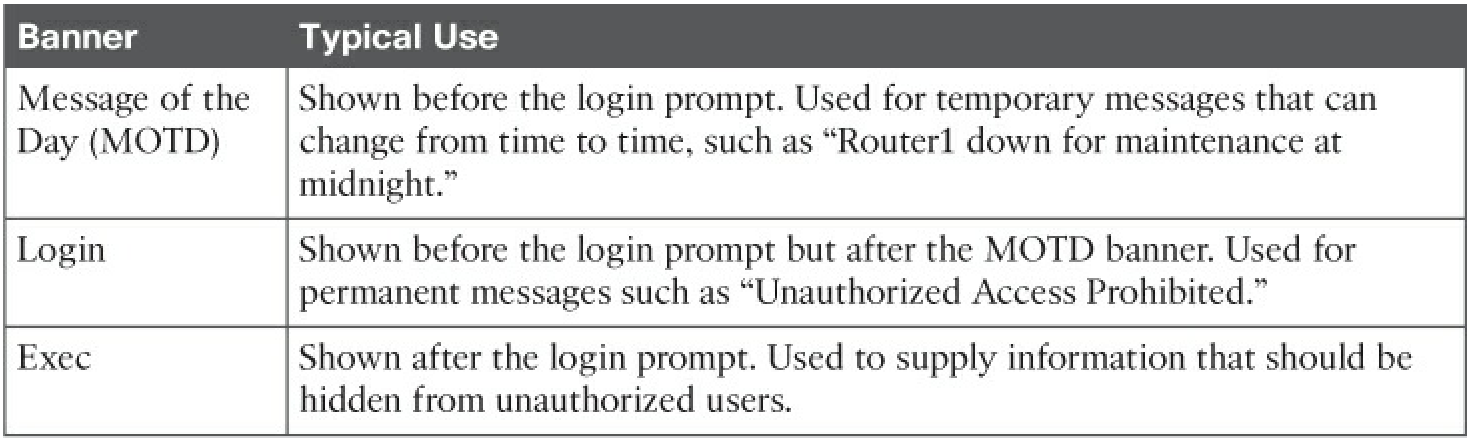
Table 7-7. Names and Purposes of the Two Main Cisco IOS Configuration Files



Configuration Filename	Purpose	Where It Is Stored
Startup config	Stores the initial configuration used anytime the switch reloads Cisco IOS.	NVRAM
Running config	Stores the currently used configuration commands. This file changes dynamically when someone enters commands in configuration mode.	RAM

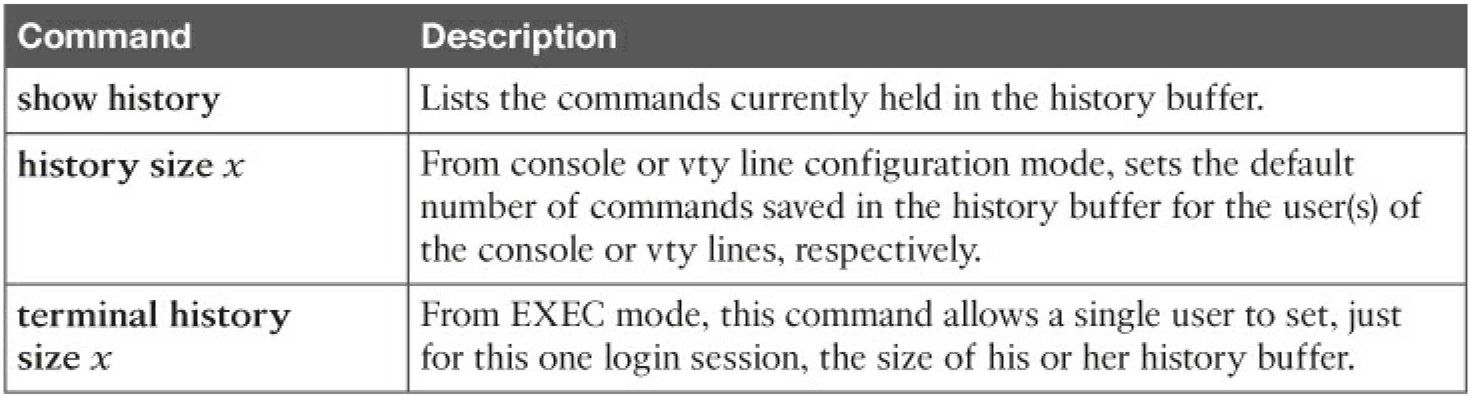
Chapter 8

Table 8-2. Banners and Their Use



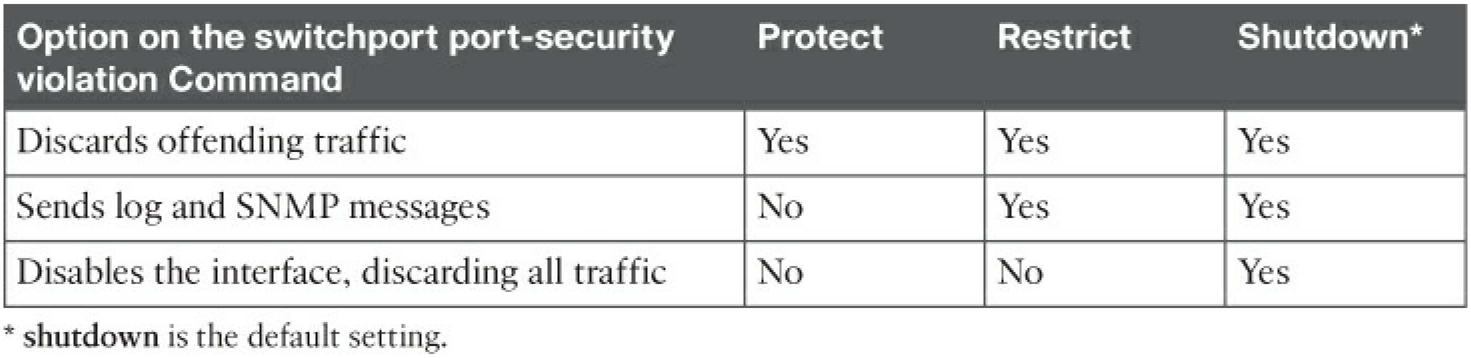
Banner	Typical Use
Message of the Day (MOTD)	Shown before the login prompt. Used for temporary messages that can change from time to time, such as "Router1 down for maintenance at midnight."
Login	Shown before the login prompt but after the MOTD banner. Used for permanent messages such as "Unauthorized Access Prohibited."
Exec	Shown after the login prompt. Used to supply information that should be hidden from unauthorized users.

Table 8-3. Commands Related to the History Buffer



Command	Description
show history	Lists the commands currently held in the history buffer.
history size *x*	From console or vty line configuration mode, sets the default number of commands saved in the history buffer for the user(s) of the console or vty lines, respectively.
terminal history size *x*	From EXEC mode, this command allows a single user to set, just for this one login session, the size of his or her history buffer.

Table 8-4. Actions When Port Security Violation Occurs

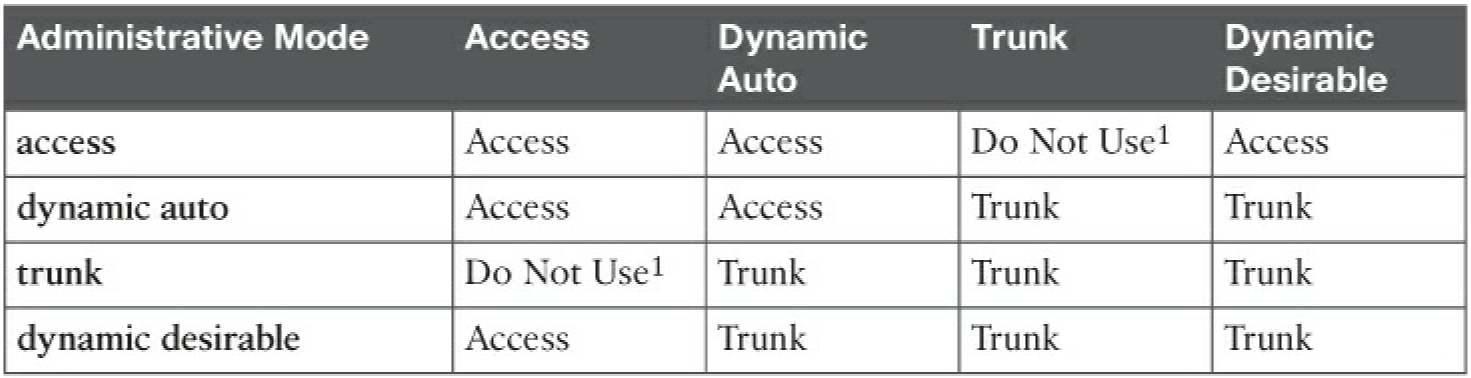


Option on the switchport port-security violation Command	Protect	Restrict	Shutdown*
Discards offending traffic	Yes	Yes	Yes
Sends log and SNMP messages	No	Yes	Yes
Disables the interface, discarding all traffic	No	No	Yes

* **shutdown** is the default setting.

Chapter 9

Table 9-3. Expected Trunking Operational Mode Based on the Configured Administrative Modes

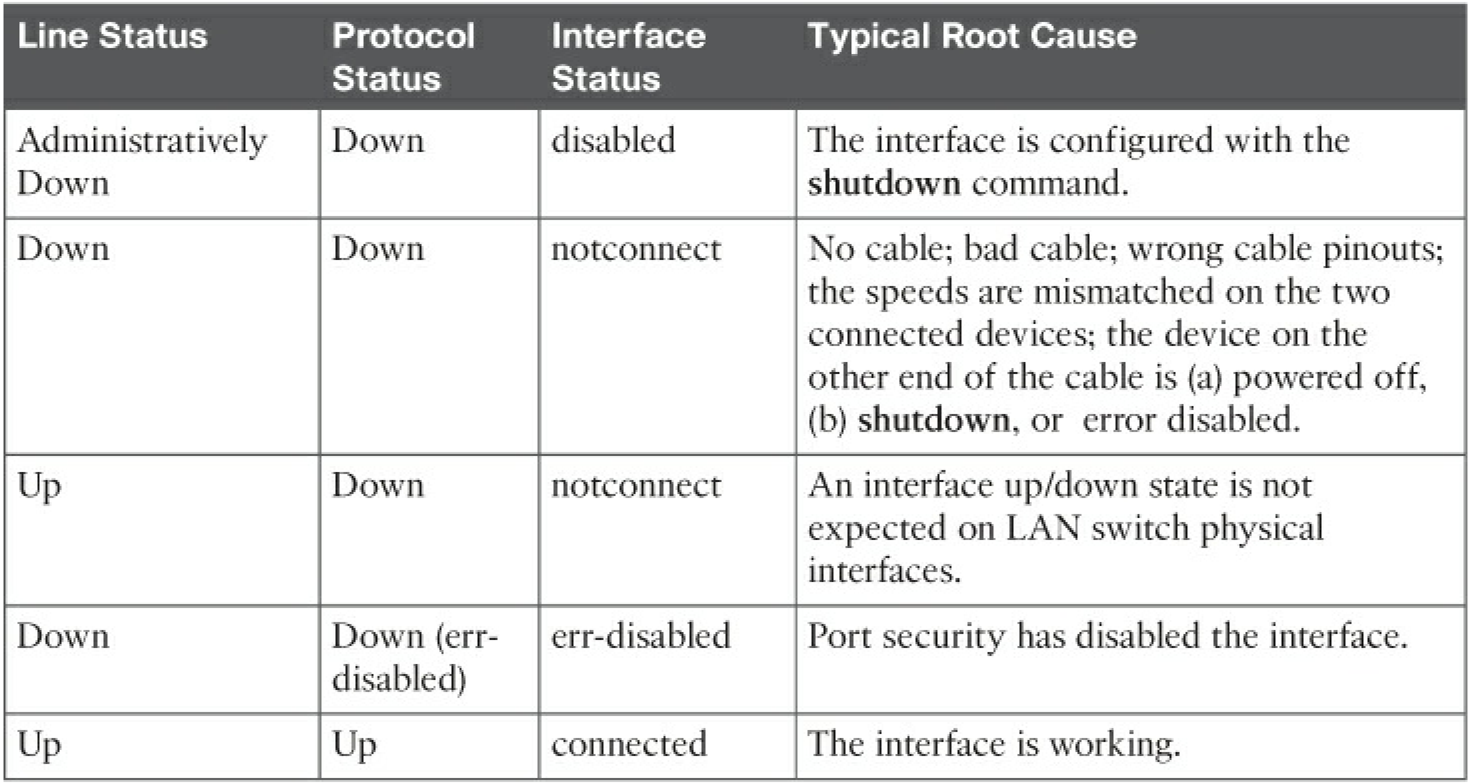


Administrative Mode	Access	Dynamic Auto	Trunk	Dynamic Desirable
access	Access	Access	Do Not Use[1]	Access
dynamic auto	Access	Access	Trunk	Trunk
trunk	Do Not Use[1]	Trunk	Trunk	Trunk
dynamic desirable	Access	Trunk	Trunk	Trunk

[1] When two switches configure a mode of "access" on one end and "trunk" on the other, problems occur. Avoid this combination.

Chapter 10

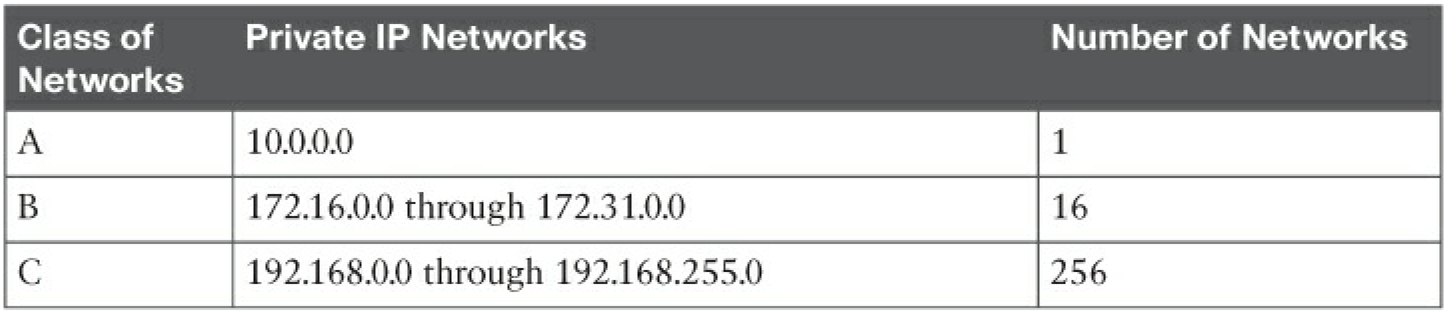
Table 10-4. LAN Switch Interface Status Codes



Line Status	Protocol Status	Interface Status	Typical Root Cause
Administratively Down	Down	disabled	The interface is configured with the **shutdown** command.
Down	Down	notconnect	No cable; bad cable; wrong cable pinouts; the speeds are mismatched on the two connected devices; the device on the other end of the cable is (a) powered off, (b) **shutdown**, or error disabled.
Up	Down	notconnect	An interface up/down state is not expected on LAN switch physical interfaces.
Down	Down (err-disabled)	err-disabled	Port security has disabled the interface.
Up	Up	connected	The interface is working.

Chapter 11

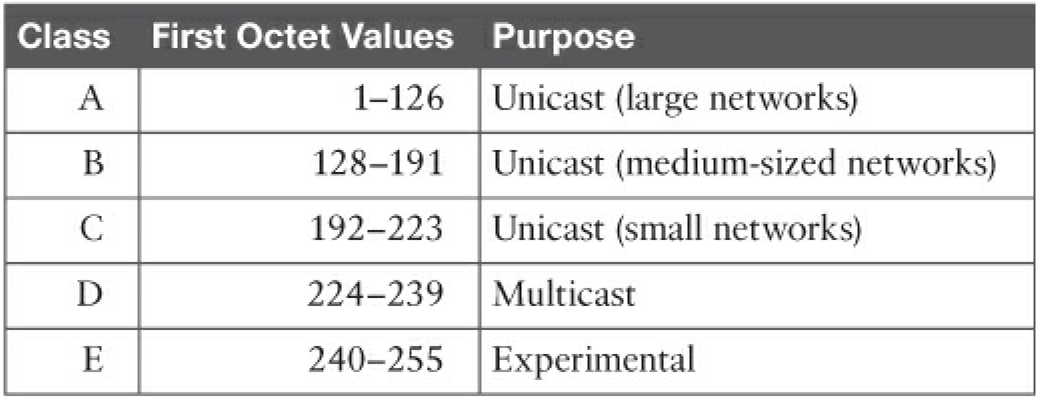
Table 11-2. RFC 1918 Private Address Space



Class of Networks	Private IP Networks	Number of Networks
A	10.0.0.0	1
B	172.16.0.0 through 172.31.0.0	16
C	192.168.0.0 through 192.168.255.0	256

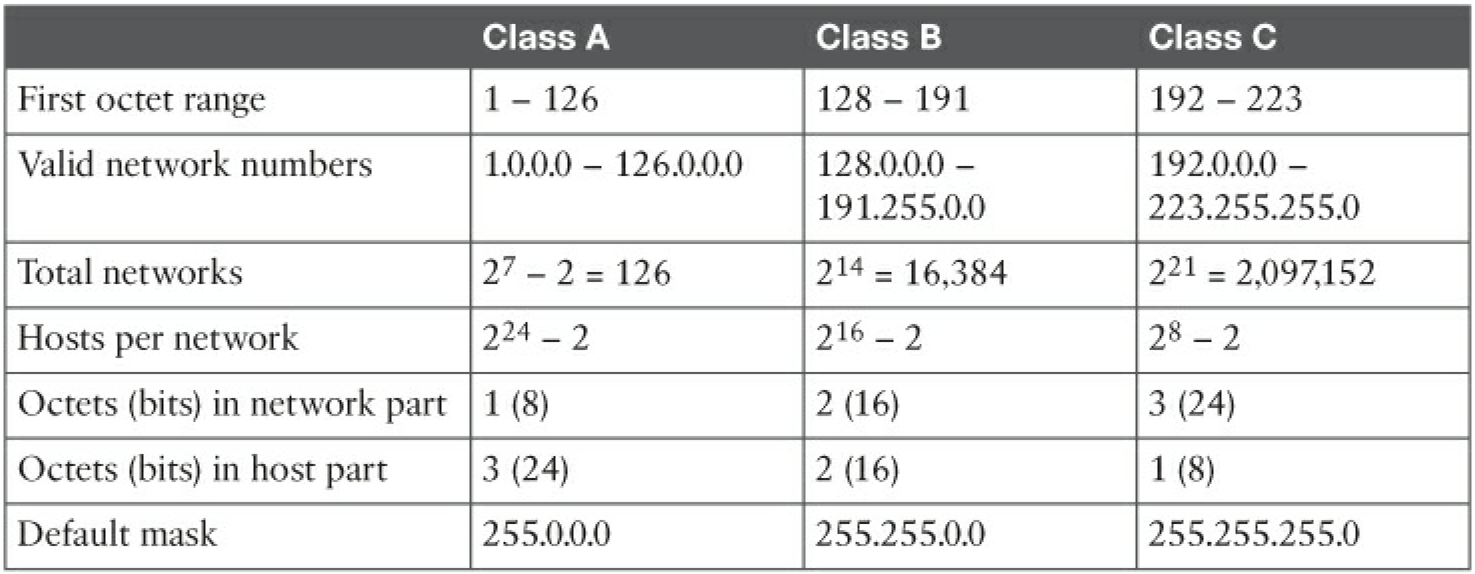
Chapter 12

Table 12-2. IPv4 Address Classes Based on First Octet Values



Class	First Octet Values	Purpose
A	1–126	Unicast (large networks)
B	128–191	Unicast (medium-sized networks)
C	192–223	Unicast (small networks)
D	224–239	Multicast
E	240–255	Experimental

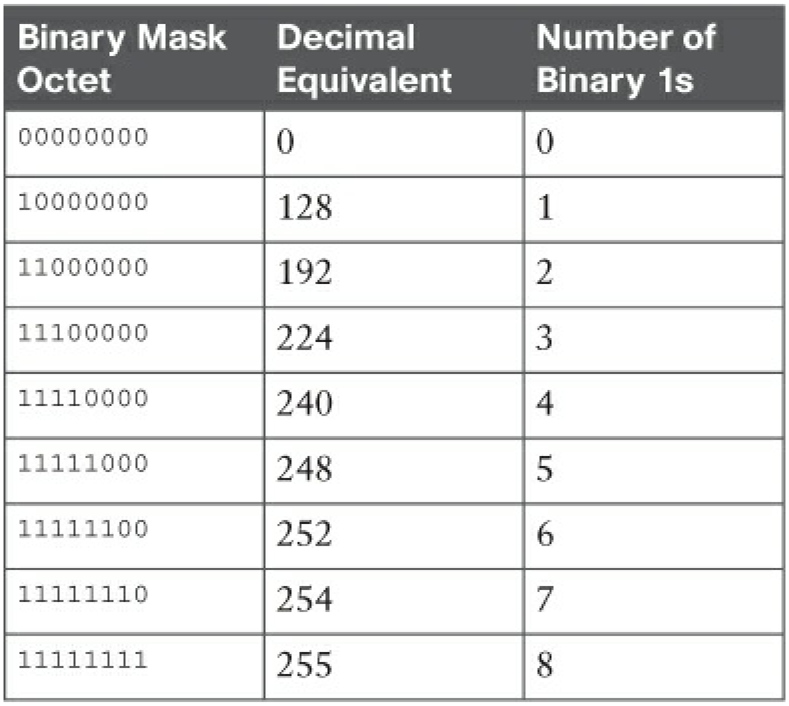
Table 12-3. Key Facts for Classes A, B, and C



	Class A	Class B	Class C
First octet range	1 – 126	128 – 191	192 – 223
Valid network numbers	1.0.0.0 – 126.0.0.0	128.0.0.0 – 191.255.0.0	192.0.0.0 – 223.255.255.0
Total networks	$2^7 - 2 = 126$	$2^{14} = 16,384$	$2^{21} = 2,097,152$
Hosts per network	$2^{24} - 2$	$2^{16} - 2$	$2^8 - 2$
Octets (bits) in network part	1 (8)	2 (16)	3 (24)
Octets (bits) in host part	3 (24)	2 (16)	1 (8)
Default mask	255.0.0.0	255.255.0.0	255.255.255.0

Chapter 13

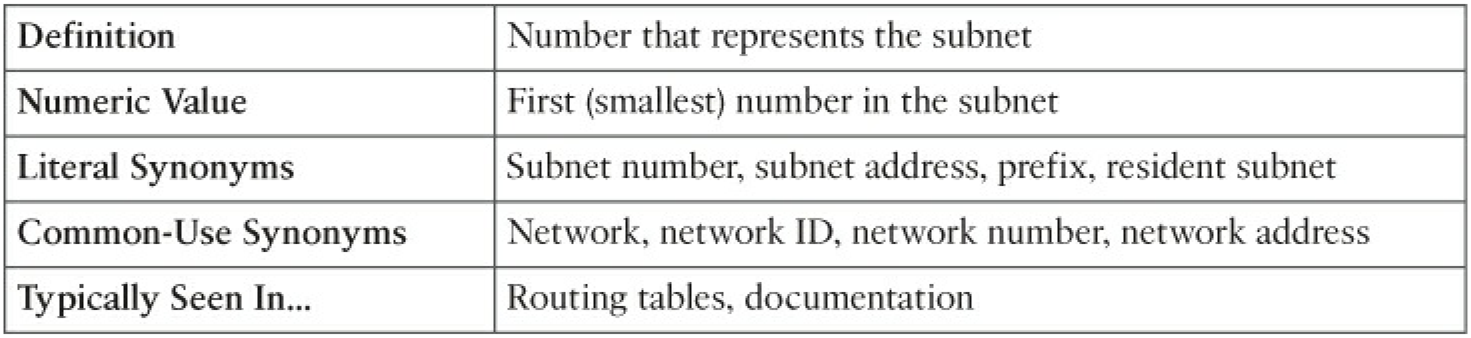
Table 13-4. Nine Possible Values in One Octet of a Subnet Mask



Binary Mask Octet	Decimal Equivalent	Number of Binary 1s
`00000000`	0	0
`10000000`	128	1
`11000000`	192	2
`11100000`	224	3
`11110000`	240	4
`11111000`	248	5
`11111100`	252	6
`11111110`	254	7
`11111111`	255	8

Chapter 14

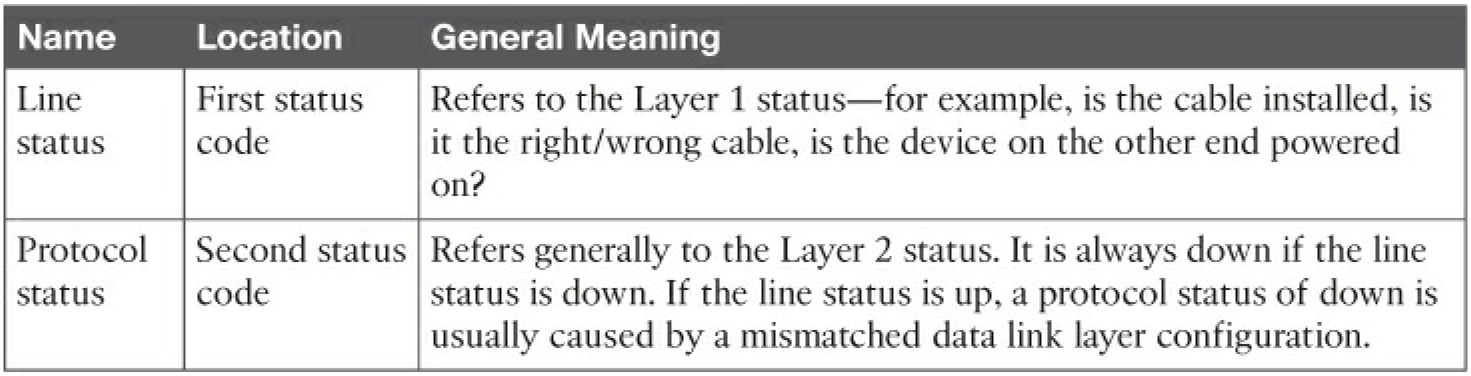
Table 14-2. Summary of Subnet ID Key Facts



Definition	Number that represents the subnet
Numeric Value	First (smallest) number in the subnet
Literal Synonyms	Subnet number, subnet address, prefix, resident subnet
Common-Use Synonyms	Network, network ID, network number, network address
Typically Seen In...	Routing tables, documentation

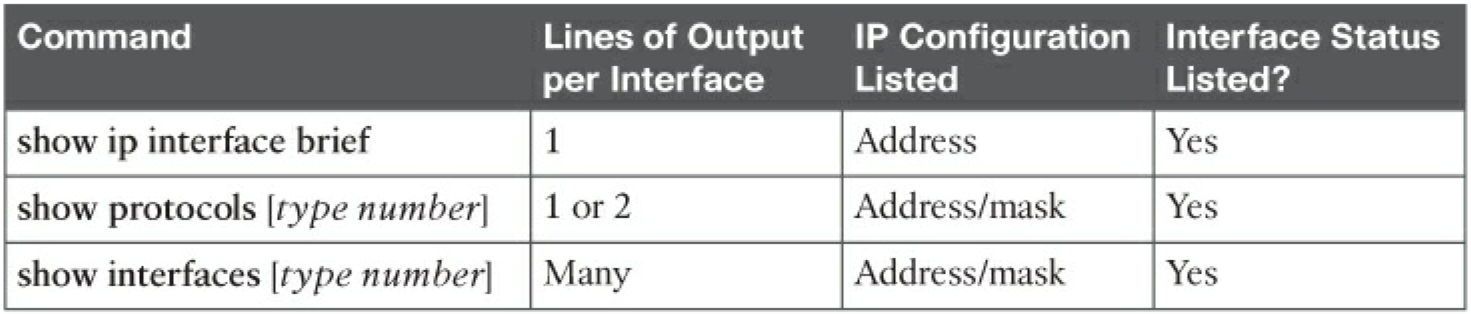
Chapter 15

Table 15-2. Interface Status Codes and Their Meanings



Name	Location	General Meaning
Line status	First status code	Refers to the Layer 1 status—for example, is the cable installed, is it the right/wrong cable, is the device on the other end powered on?
Protocol status	Second status code	Refers generally to the Layer 2 status. It is always down if the line status is down. If the line status is up, a protocol status of down is usually caused by a mismatched data link layer configuration.

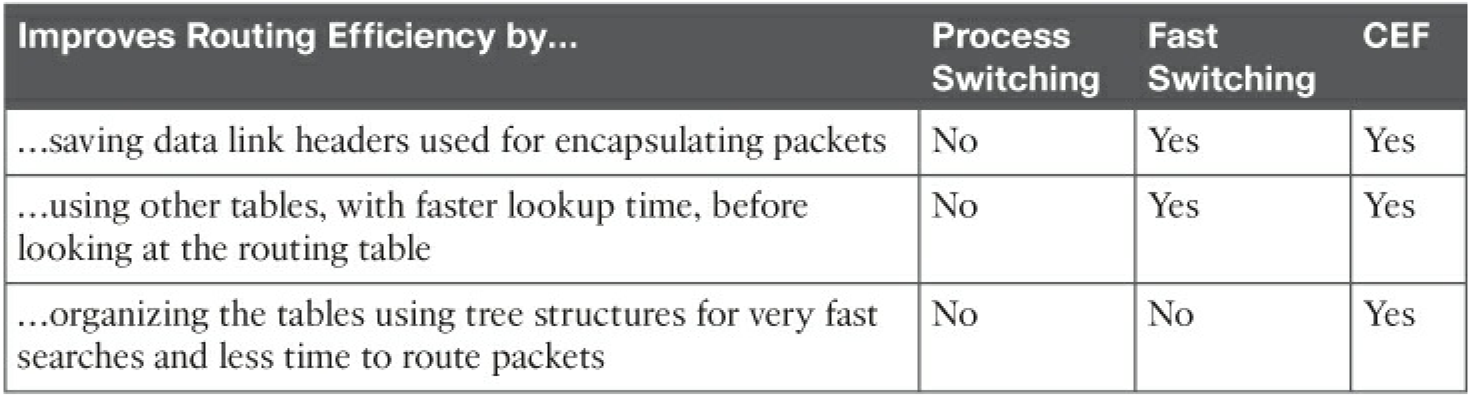
Table 15-4. Key Commands to List Router Interface Status



Command	Lines of Output per Interface	IP Configuration Listed	Interface Status Listed?
show ip interface brief	1	Address	Yes
show protocols [*type number*]	1 or 2	Address/mask	Yes
show interfaces [*type number*]	Many	Address/mask	Yes

Chapter 16

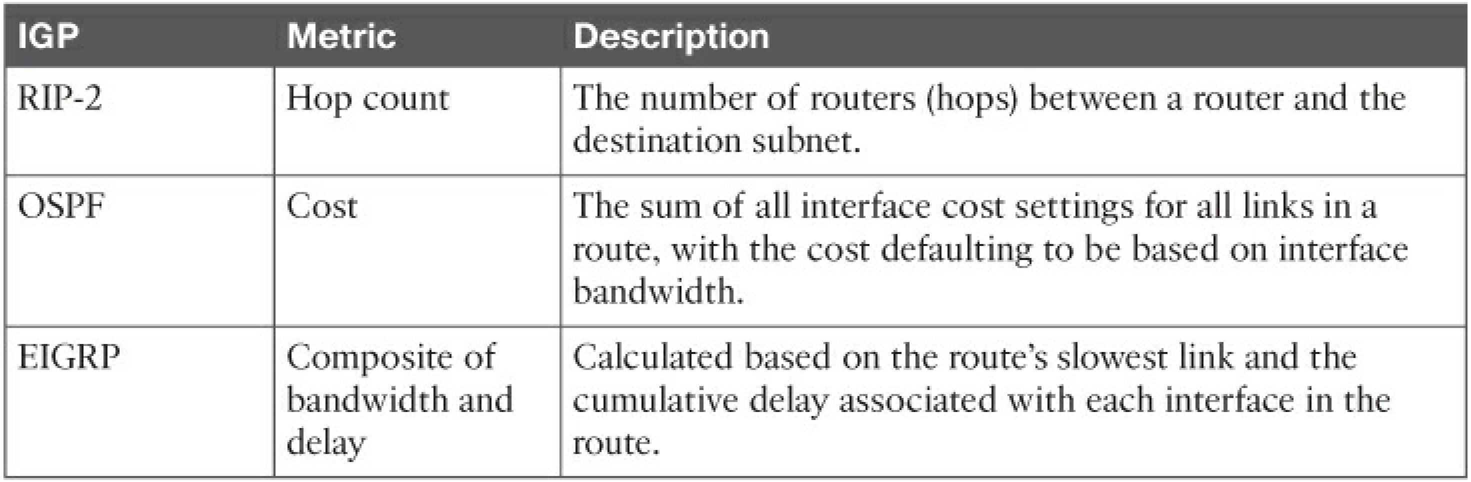
Table 16-2. Comparisons of Packet Switching, Fast Switching, and CEF



Improves Routing Efficiency by...	Process Switching	Fast Switching	CEF
...saving data link headers used for encapsulating packets	No	Yes	Yes
...using other tables, with faster lookup time, before looking at the routing table	No	Yes	Yes
...organizing the tables using tree structures for very fast searches and less time to route packets	No	No	Yes

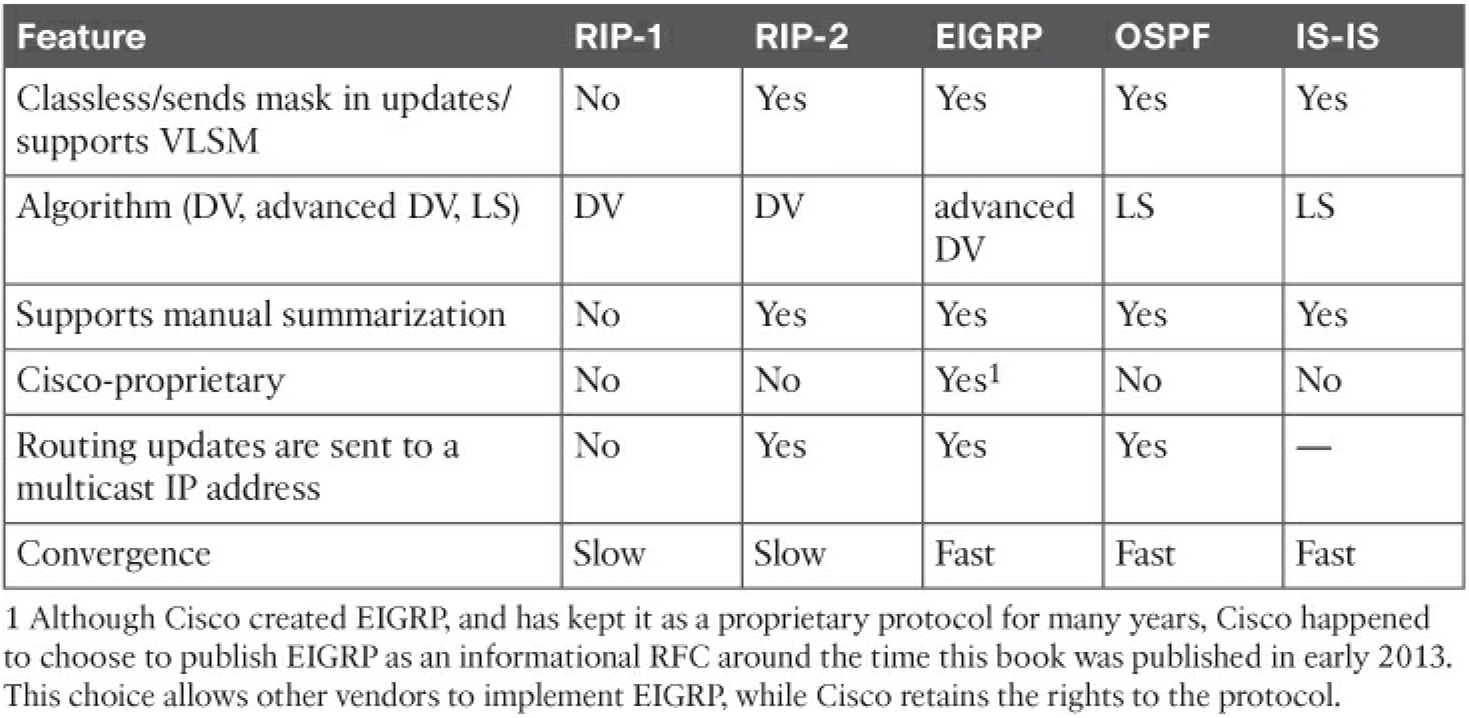
Chapter 17

Table 17-2. IP IGP Metrics



IGP	Metric	Description
RIP-2	Hop count	The number of routers (hops) between a router and the destination subnet.
OSPF	Cost	The sum of all interface cost settings for all links in a route, with the cost defaulting to be based on interface bandwidth.
EIGRP	Composite of bandwidth and delay	Calculated based on the route's slowest link and the cumulative delay associated with each interface in the route.

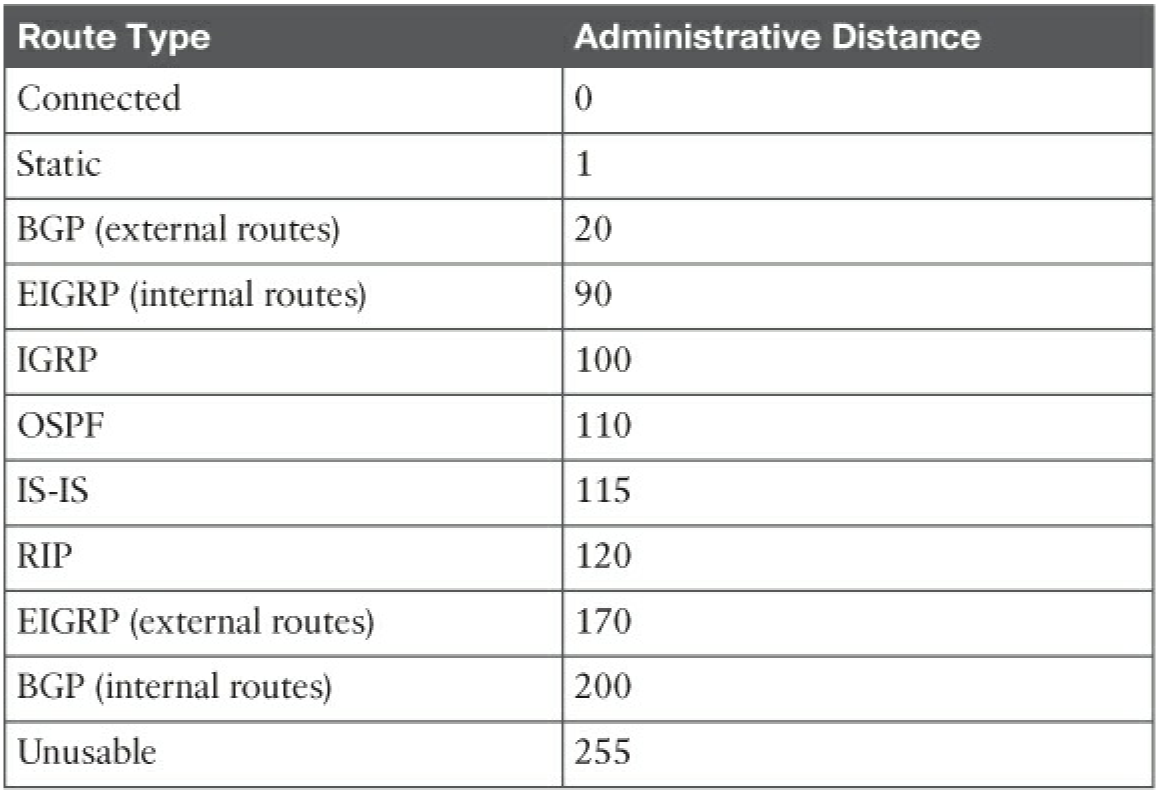
Table 17-3. Interior IP Routing Protocols Compared



Feature	RIP-1	RIP-2	EIGRP	OSPF	IS-IS
Classless/sends mask in updates/ supports VLSM	No	Yes	Yes	Yes	Yes
Algorithm (DV, advanced DV, LS)	DV	DV	advanced DV	LS	LS
Supports manual summarization	No	Yes	Yes	Yes	Yes
Cisco-proprietary	No	No	Yes[1]	No	No
Routing updates are sent to a multicast IP address	No	Yes	Yes	Yes	—
Convergence	Slow	Slow	Fast	Fast	Fast

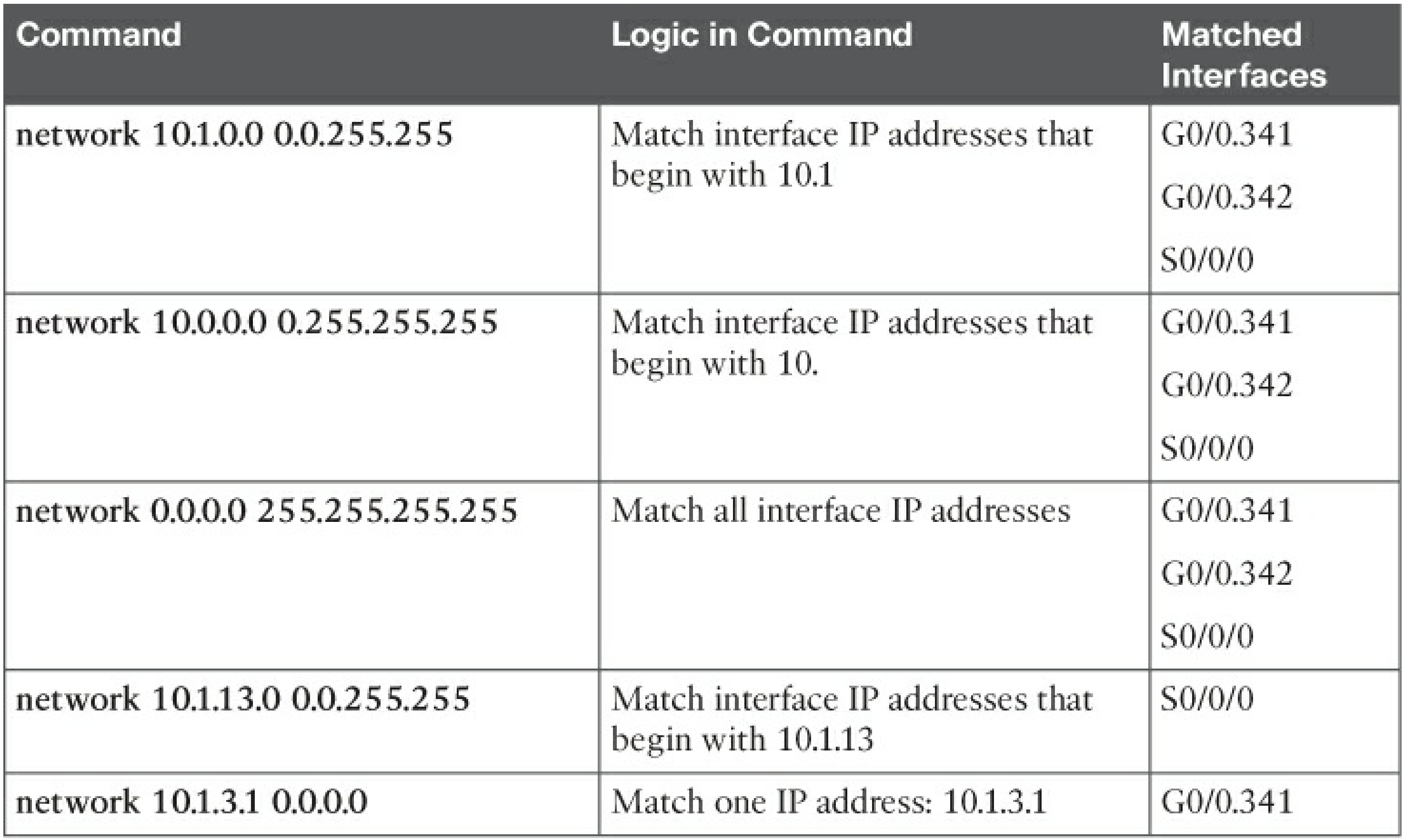
1 Although Cisco created EIGRP, and has kept it as a proprietary protocol for many years, Cisco happened to choose to publish EIGRP as an informational RFC around the time this book was published in early 2013. This choice allows other vendors to implement EIGRP, while Cisco retains the rights to the protocol.

Table 17-4. Default Administrative Distances



Route Type	Administrative Distance
Connected	0
Static	1
BGP (external routes)	20
EIGRP (internal routes)	90
IGRP	100
OSPF	110
IS-IS	115
RIP	120
EIGRP (external routes)	170
BGP (internal routes)	200
Unusable	255

Table 17-5. Example OSPF network **Commands on R3, with Expected Results**



Command	Logic in Command	Matched Interfaces
network 10.1.0.0 0.0.255.255	Match interface IP addresses that begin with 10.1	G0/0.341 G0/0.342 S0/0/0
network 10.0.0.0 0.255.255.255	Match interface IP addresses that begin with 10.	G0/0.341 G0/0.342 S0/0/0
network 0.0.0.0 255.255.255.255	Match all interface IP addresses	G0/0.341 G0/0.342 S0/0/0
network 10.1.13.0 0.0.255.255	Match interface IP addresses that begin with 10.1.13	S0/0/0
network 10.1.3.1 0.0.0.0	Match one IP address: 10.1.3.1	G0/0.341

Chapter 20

Table 20-2. Classless and Classful Interior IP Routing Protocols

Routing Protocol	Is It Classless?	Sends Mask in Updates?	Supports VLSM?	Supports Manual Route Summarization?
RIP-1	No	No	No	No
IGRP	No	No	No	No
RIP-2	Yes	Yes	Yes	Yes
EIGRP	Yes	Yes	Yes	Yes
OSPF	Yes	Yes	Yes	Yes

Chapter 24

Table 24-2. RFC 1918 Private Address Space

Range of IP Addresses	Class of Networks	Number of Networks
10.0.0.0 to 10.255.255.255	A	1
172.16.0.0 to 172.31.255.255	B	16
192.168.0.0 to 192.168.255.255	C	256

Chapter 25

Table 25-3. Hexadecimal/Binary Conversion Chart

Hex	Binary	Hex	Binary
0	0000	8	1000
1	0001	9	1001
2	0010	A	1010
3	0011	B	1011
4	0100	C	1100
5	0101	D	1101
6	0110	E	1110
7	0111	F	1111

Chapter 26

Table 26-2. Some Types of IPv6 Addresses and Their First Hex Digit(s)

Address Type	First Hex Digits
Global Unicast	2 or 3 (originally); all not otherwise reserved (today)
Unique Local	FD
Multicast	FF
Link-Local	FE80

Chapter 27

Table 27-3. Key IPv6 Local-Scope Multicast Addresses

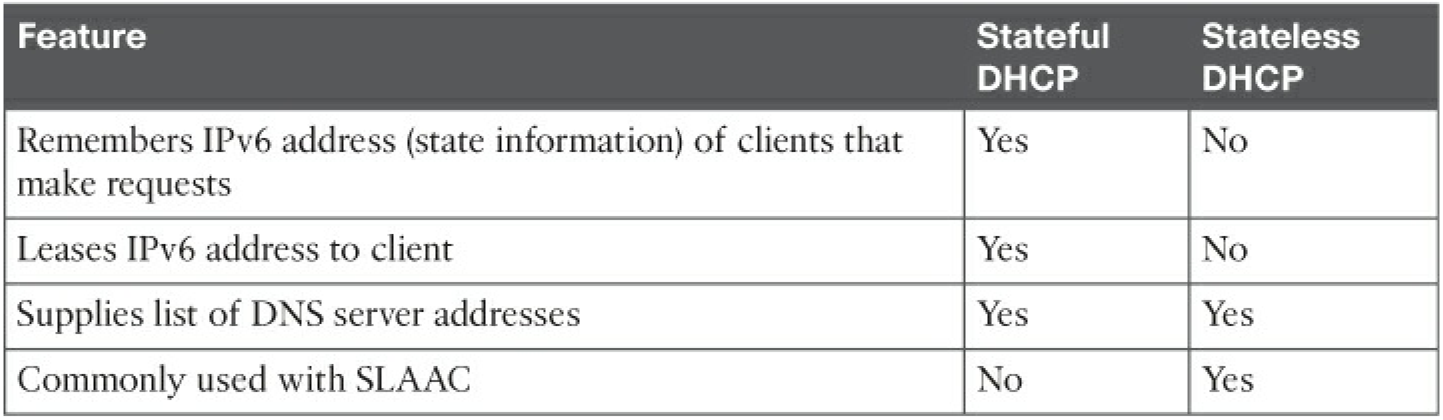
Short Name	Multicast Address	Meaning	IPv4 Equivalent
All-nodes	FF02::1	All-nodes (all interfaces that use IPv6 that are on the link)	A subnet broadcast address
All-routers	FF02::2	All-routers (all IPv6 router interfaces on the link)	None
All-OSPF, All-OSPF-DR	FF02::5, FF02::6	All OSPF routers and all OSPF designated routers, respectively	224.0.0.5, 224.0.0.6
EIGRPv6 Routers	FF02::A	All routers using EIGRP for IPv6 (EIGRPv6)	224.0.0.10

Chapter 28

Table 28-2. NDP Function Summary

Function	Protocol Messages	Who Discovers Info	Who Supplies Info	Info Supplied
Router discovery	RS and RA	Any IPv6 host	Any IPv6 router	Link-local IPv6 address of router
Prefix/length discovery	RS and RA	Any IPv6 host	Any IPv6 router	Prefix(es) and associated prefix lengths used on local link
Neighbor discovery	NS and NA	Any IPv6 host	Any IPv6 host	Link-layer address (for example, MAC address) used by a neighbor
Duplicate Address Detection	NS and NA	Any IPv6 host	Any IPv6 host	Simple confirmation whether a unicast address is already in use

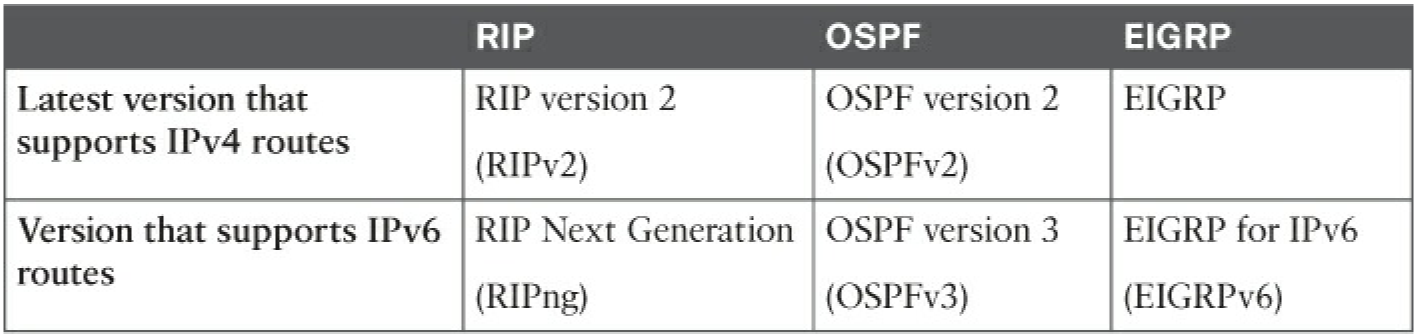
Table 28-3. Comparison of Stateless and Stateful DHCPv6 Services



Feature	Stateful DHCP	Stateless DHCP
Remembers IPv6 address (state information) of clients that make requests	Yes	No
Leases IPv6 address to client	Yes	No
Supplies list of DNS server addresses	Yes	Yes
Commonly used with SLAAC	No	Yes

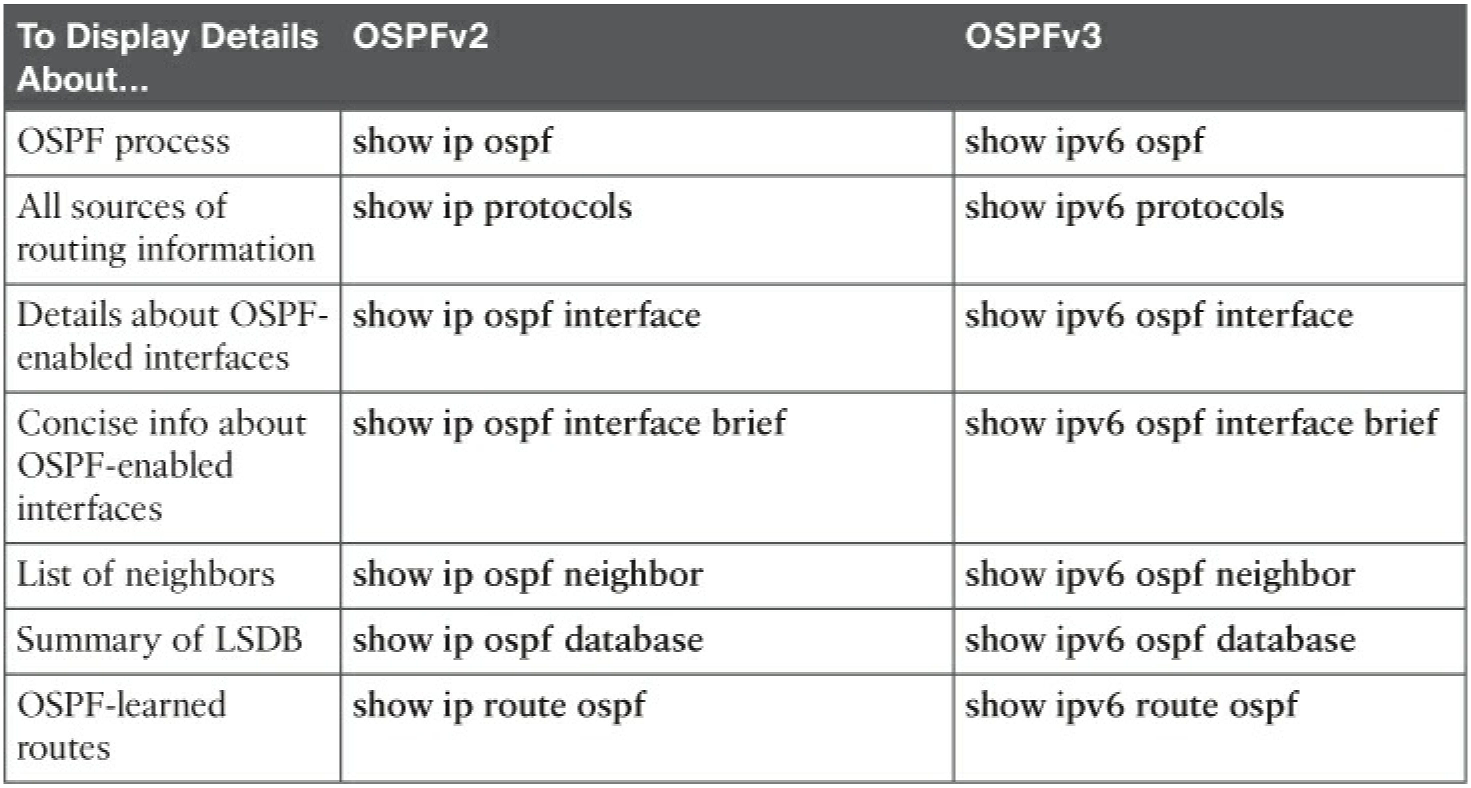
Chapter 29

Table 29-2. Summary of Version Terminology for Interior Routing Protocols



	RIP	OSPF	EIGRP
Latest version that supports IPv4 routes	RIP version 2 (RIPv2)	OSPF version 2 (OSPFv2)	EIGRP
Version that supports IPv6 routes	RIP Next Generation (RIPng)	OSPF version 3 (OSPFv3)	EIGRP for IPv6 (EIGRPv6)

Table 29-3. OSPFv2 and Matching OSPFv3 show **Commands**



To Display Details About...	OSPFv2	OSPFv3
OSPF process	**show ip ospf**	**show ipv6 ospf**
All sources of routing information	**show ip protocols**	**show ipv6 protocols**
Details about OSPF-enabled interfaces	**show ip ospf interface**	**show ipv6 ospf interface**
Concise info about OSPF-enabled interfaces	**show ip ospf interface brief**	**show ipv6 ospf interface brief**
List of neighbors	**show ip ospf neighbor**	**show ipv6 ospf neighbor**
Summary of LSDB	**show ip ospf database**	**show ipv6 ospf database**
OSPF-learned routes	**show ip route ospf**	**show ipv6 route ospf**

Appendix O. Mind Map Solutions

This appendix provides solutions to the mind map exercises in the Part Review exercises. You can also find files of these solutions in PDF and XMIND format on the DVD. (The sample mind maps on the download page use the XMIND application [www.xmind.net], which at the time of publication, supported free versions on Windows, Mac, and Linux.)

Part I Review Mind Map Solution

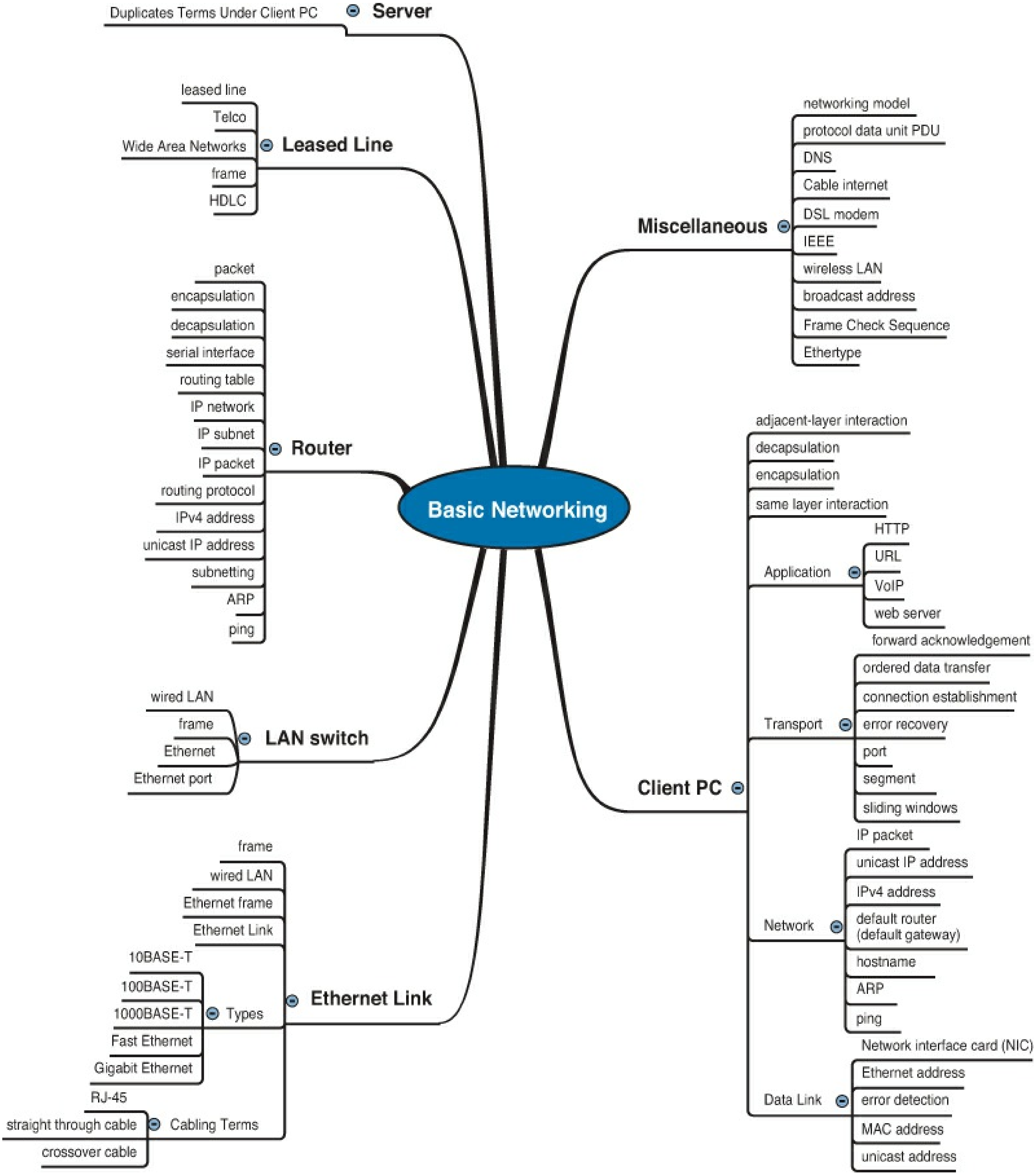

Basic Networking
Server
Duplicates Terms Under Client PC
Leased Line
leased line
Telco
Wide Area Networks
frame
HDLC
Router
packet
encapsulation
decapsulation
serial interface
routing table
IP network
IP subnet
IP packet
routing protocol
IPv4 address
unicast IP address
subnetting
ARP
ping
LAN switch
wired LAN
frame
Ethernet
Ethernet port
Ethernet Link
frame
wired LAN
Ethernet frame
Ethernet Link
Types
10BASE-T
100BASE-T
1000BASE-T
Fast Ethernet
Gigabit Ethernet
Cabling Terms
RJ-45
straight through cable
crossover cable
Miscellaneous
networking model
protocol data unit PDU
DNS
Cable internet
DSL modem
IEEE
wireless LAN
broadcast address
Frame Check Sequence
Ethertype
Client PC
adjacent-layer interaction
decapsulation
encapsulation
same layer interaction
Application
HTTP
URL
VoIP
web server
Transport
forward acknowledgement
ordered data transfer
connection establishment
error recovery
port
segment
sliding windows
Network
IP packet
unicast IP address
IPv4 address
default router (default gateway)
hostname
ARP
ping
Data Link
Network interface card (NIC)
Ethernet address
error detection
MAC address
unicast address

Figure O-1. Part I Review Mind Map Solution

Part II Review Mind Map Solution

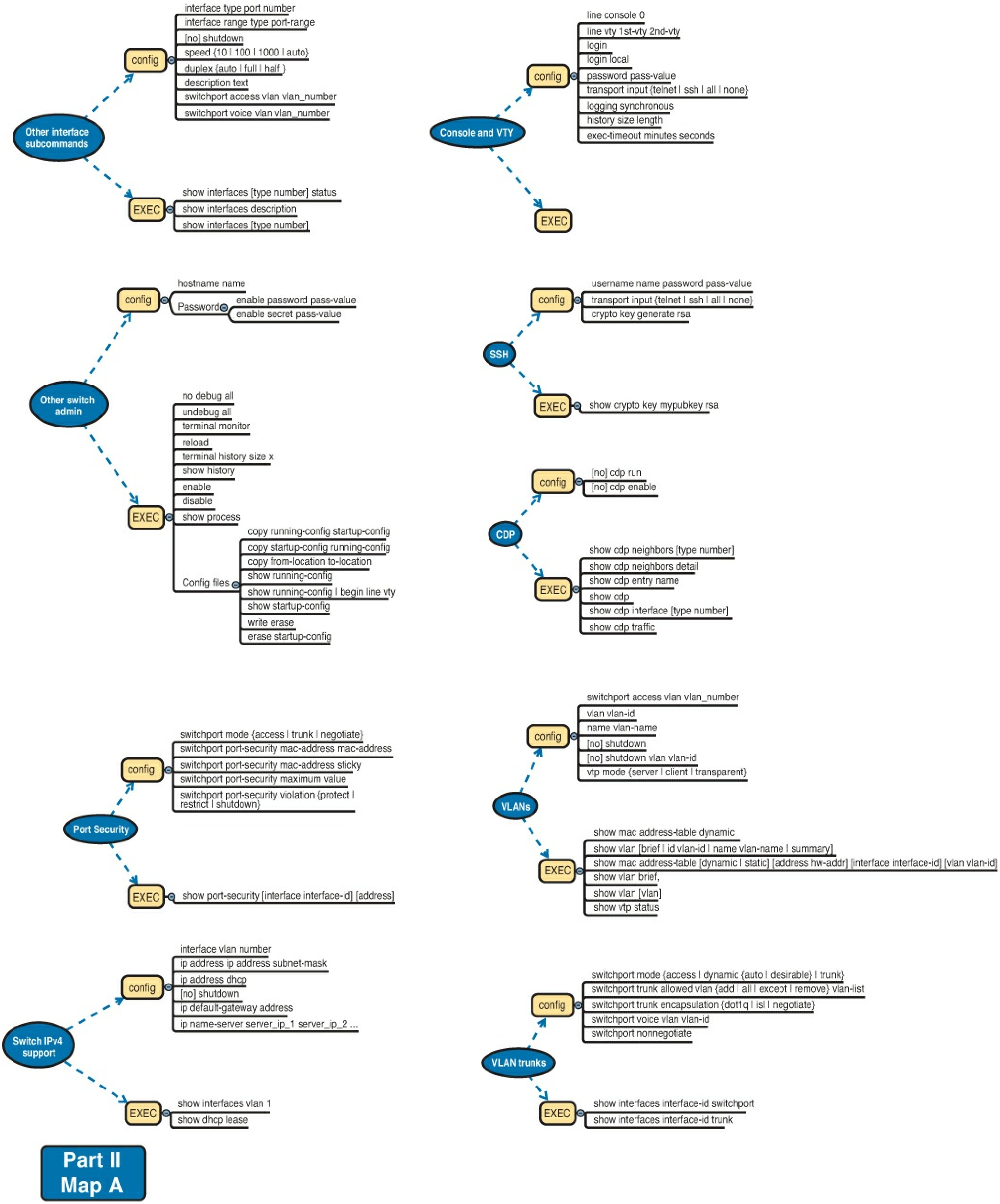
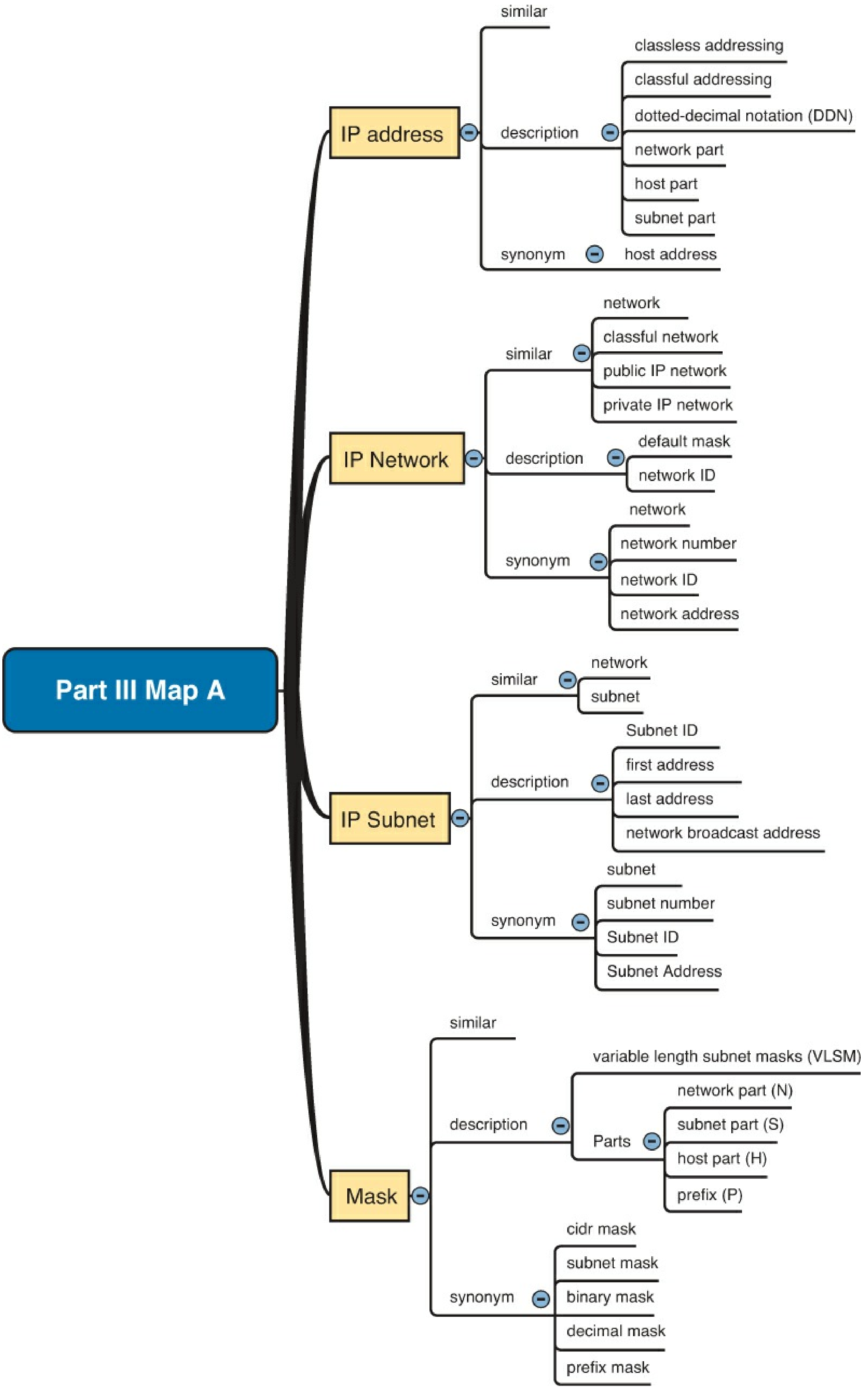
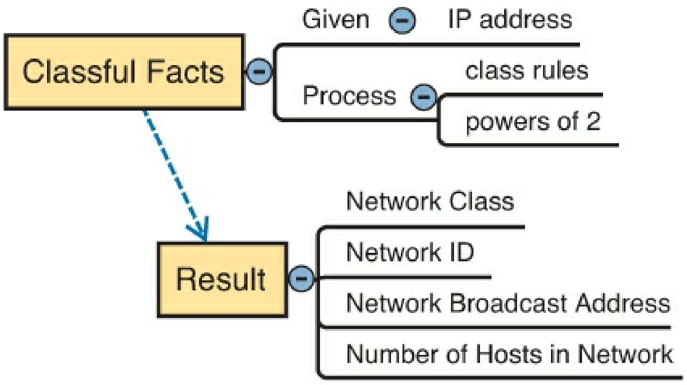
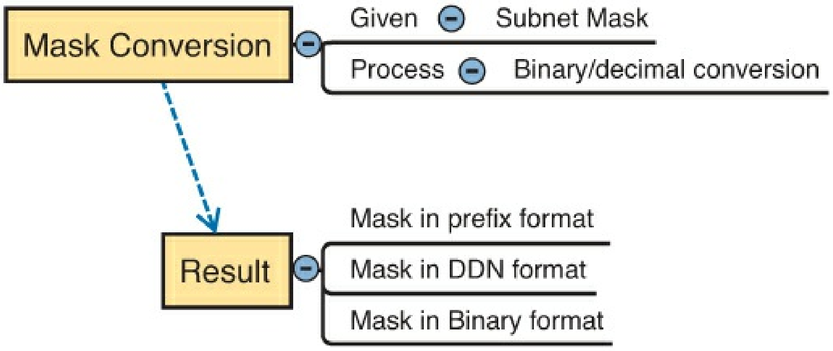

Other interface subcommands
config
interface type port number
interface range type port-range
[no] shutdown
speed {10 | 100 | 1000 | auto}
duplex {auto | full | half }
description text
switchport access vlan vlan_number
switchport voice vlan vlan_number
EXEC
show interfaces [type number] status
show interfaces description
show interfaces [type number]
Console and VTY
config
line console 0
line vty 1st-vty 2nd-vty
login
login local
password pass-value
transport input {telnet | ssh | all | none}
logging synchronous
history size length
exec-timeout minutes seconds
EXEC
Other switch admin
config
hostname name
Password
enable password pass-value
enable secret pass-value
EXEC
no debug all
undebug all
terminal monitor
reload
terminal history size x
show history
enable
disable
show process
Config files
copy running-config startup-config
copy startup-config running-config
copy from-location to-location
show running-config
show running-config | begin line vty
show startup-config
write erase
erase startup-config
SSH
config
username name password pass-value
transport input {telnet | ssh | all | none}
crypto key generate rsa
EXEC
show crypto key mypubkey rsa
CDP
config
[no] cdp run
[no] cdp enable
EXEC
show cdp neighbors [type number]
show cdp neighbors detail
show cdp entry name
show cdp
show cdp interface [type number]
show cdp traffic
Port Security
config
switchport mode {access | trunk | negotiate}
switchport port-security mac-address mac-address
switchport port-security mac-address sticky
switchport port-security maximum value
switchport port-security violation {protect | restrict | shutdown}
EXEC
show port-security [interface interface-id] [address]
VLANs
config
switchport access vlan vlan_number
vlan vlan-id
name vlan-name
[no] shutdown
[no] shutdown vlan vlan-id
vtp mode {server | client | transparent}
EXEC
show mac address-table dynamic
show vlan [brief | id vlan-id | name vlan-name | summary]
show mac address-table [dynamic | static] [address hw-addr] [interface interface-id] [vlan vlan-id]
show vlan brief,
show vlan [vlan]
show vtp status
Switch IPv4 support
config
interface vlan number
ip address ip address subnet-mask
ip address dhcp
[no] shutdown
ip default-gateway address
ip name-server server_ip_1 server_ip_2 ...
EXEC
show interfaces vlan 1
show dhcp lease
VLAN trunks
config
switchport mode {access | dynamic {auto | desirable} | trunk}
switchport trunk allowed vlan {add | all | except | remove} vlan-list
switchport trunk encapsulation {dot1q | isl | negotiate}
switchport voice vlan vlan-id
switchport nonnegotiate
EXEC
show interfaces interface-id switchport
show interfaces interface-id trunk
Part II Map A

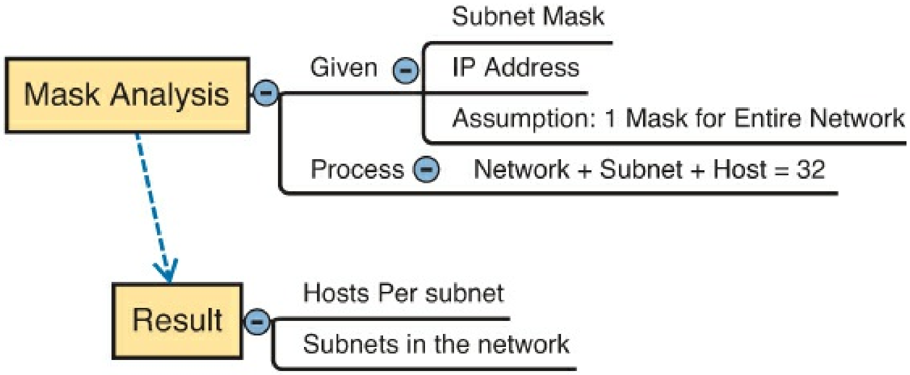
Figure O-2. Part II Review Mind Map Solution

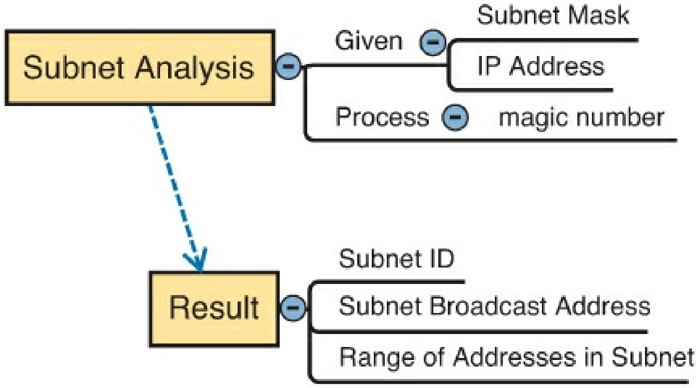
Part III Review Mind Map Solutions


Part III Map A
IP address
similar
description
classless addressing
classful addressing
dotted-decimal notation (DDN)
network part
host part
subnet part
synonym
host address
IP Network
similar
network
classful network
public IP network
private IP network
description
default mask
network ID
synonym
network
network number
network ID
network address
IP Subnet
similar
network
subnet
description
Subnet ID
first address
last address
network broadcast address
synonym
subnet
subnet number
Subnet ID
Subnet Address
Mask
similar
description
variable length subnet masks (VLSM)
Parts
network part (N)
subnet part (S)
host part (H)
prefix (P)
synonym
cidr mask
subnet mask
binary mask
decimal mask
prefix mask


Classful Facts
Given
IP address
Process
class rules
powers of 2
Result
Network Class
Network ID
Network Broadcast Address
Number of Hosts in Network


Mask Conversion
Given
Subnet Mask
Process
Binary/decimal conversion
Result
Mask in prefix format
Mask in DDN format
Mask in Binary format


Mask Analysis
Given
Subnet Mask
IP Address
Assumption: 1 Mask for Entire Network
Process
Network + Subnet + Host = 32
Result
Hosts Per subnet
Subnets in the network

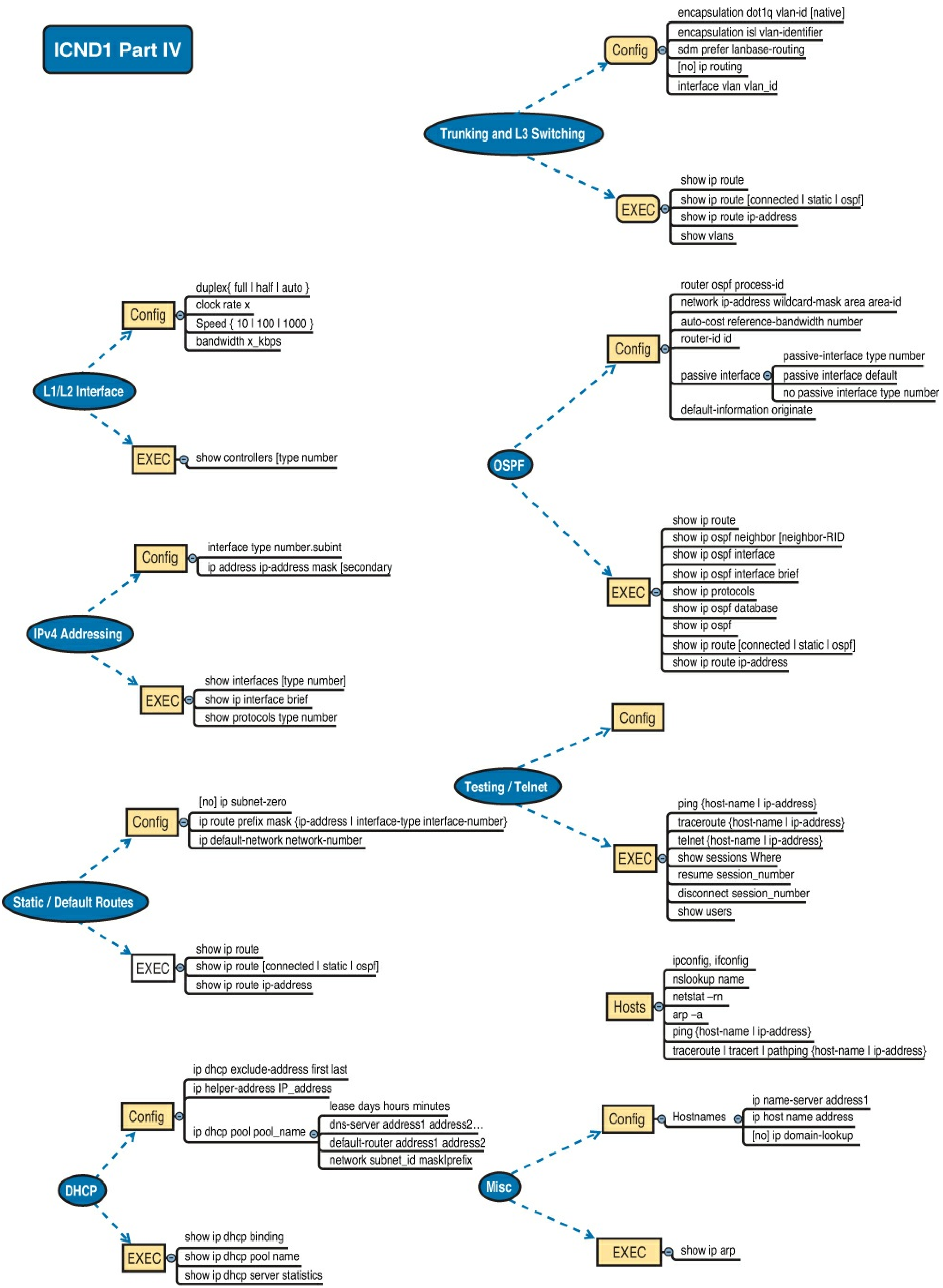

Subnet Analysis
Given
Subnet Mask
IP Address
Process
magic number
Result
Subnet ID
Subnet Broadcast Address
Range of Addresses in Subnet

Part III Map B

Part IV Review Mind Map Solution

Figure O-4. Part III Review Mind Map Solution B

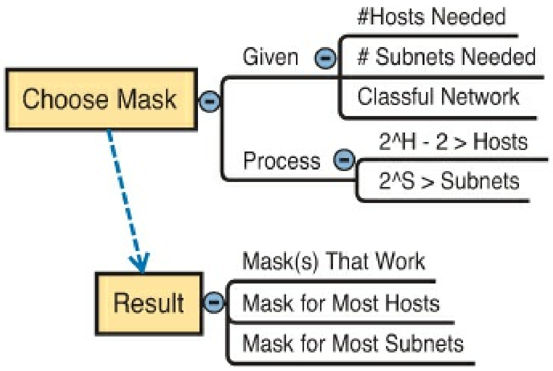
ICND1 Part IV

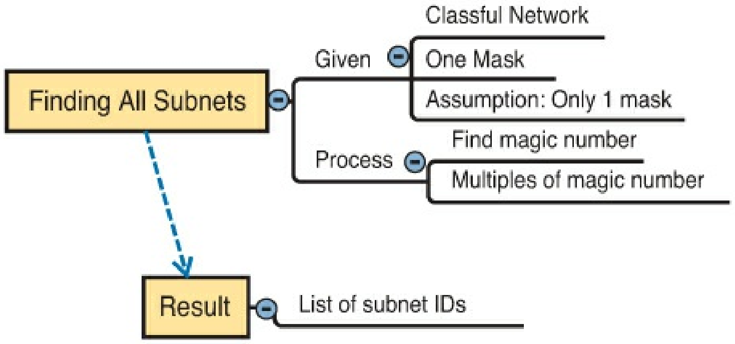


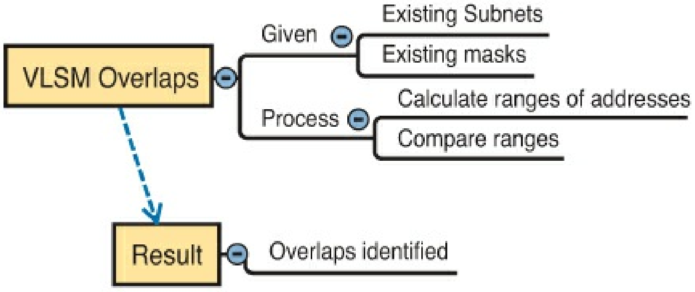
- **L1/L2 Interface**
  - Config
    - duplex{ full | half | auto }
    - clock rate x
    - Speed { 10 | 100 | 1000 }
    - bandwidth x_kbps
  - EXEC
    - show controllers [type number
- **IPv4 Addressing**
  - Config
    - interface type number.subint
    - ip address ip-address mask [secondary
  - EXEC
    - show interfaces [type number]
    - show ip interface brief
    - show protocols type number
- **Static / Default Routes**
  - Config
    - [no] ip subnet-zero
    - ip route prefix mask {ip-address | interface-type interface-number}
    - ip default-network network-number
  - EXEC
    - show ip route
    - show ip route [connected | static | ospf]
    - show ip route ip-address
- **DHCP**
  - Config
    - ip dhcp exclude-address first last
    - ip helper-address IP_address
    - ip dhcp pool pool_name
      - lease days hours minutes
      - dns-server address1 address2…
      - default-router address1 address2
      - network subnet_id mask|prefix
  - EXEC
    - show ip dhcp binding
    - show ip dhcp pool name
    - show ip dhcp server statistics
- **Trunking and L3 Switching**
  - Config
    - encapsulation dot1q vlan-id [native]
    - encapsulation isl vlan-identifier
    - sdm prefer lanbase-routing
    - [no] ip routing
    - interface vlan vlan_id
  - EXEC
    - show ip route
    - show ip route [connected | static | ospf]
    - show ip route ip-address
    - show vlans
- **OSPF**
  - Config
    - router ospf process-id
    - network ip-address wildcard-mask area area-id
    - auto-cost reference-bandwidth number
    - router-id id
    - passive interface
      - passive-interface type number
      - passive interface default
      - no passive interface type number
    - default-information originate
  - EXEC
    - show ip route
    - show ip ospf neighbor [neighbor-RID
    - show ip ospf interface
    - show ip ospf interface brief
    - show ip protocols
    - show ip ospf database
    - show ip ospf
    - show ip route [connected | static | ospf]
    - show ip route ip-address
- **Testing / Telnet**
  - Config
  - EXEC
    - ping {host-name | ip-address}
    - traceroute {host-name | ip-address}
    - telnet {host-name | ip-address}
    - show sessions Where
    - resume session_number
    - disconnect session_number
    - show users
  - Hosts
    - ipconfig, ifconfig
    - nslookup name
    - netstat –rn
    - arp –a
    - ping {host-name | ip-address}
    - traceroute | tracert | pathping {host-name | ip-address}
- **Misc**
  - Config
    - Hostnames
      - ip name-server address1
      - ip host name address
      - [no] ip domain-lookup
  - EXEC
    - show ip arp

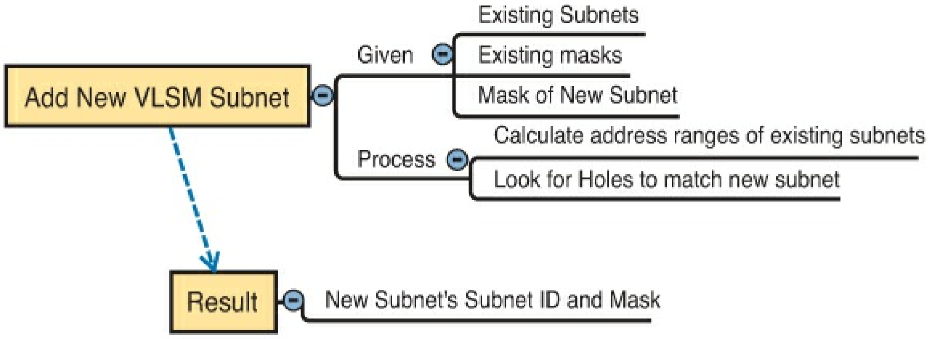
Part V Review Mind Map Solution

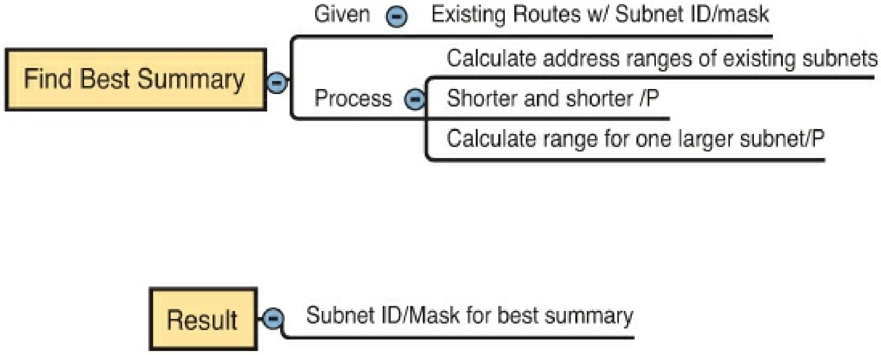
Figure O-5. Part IV Review Mind Map Solution


Choose Mask
Given
#Hosts Needed
# Subnets Needed
Classful Network
Process
2^H - 2 > Hosts
2^S > Subnets
Result
Mask(s) That Work
Mask for Most Hosts
Mask for Most Subnets


Finding All Subnets
Given
Classful Network
One Mask
Assumption: Only 1 mask
Process
Find magic number
Multiples of magic number
Result
List of subnet IDs


VLSM Overlaps
Given
Existing Subnets
Existing masks
Process
Calculate ranges of addresses
Compare ranges
Result
Overlaps identified

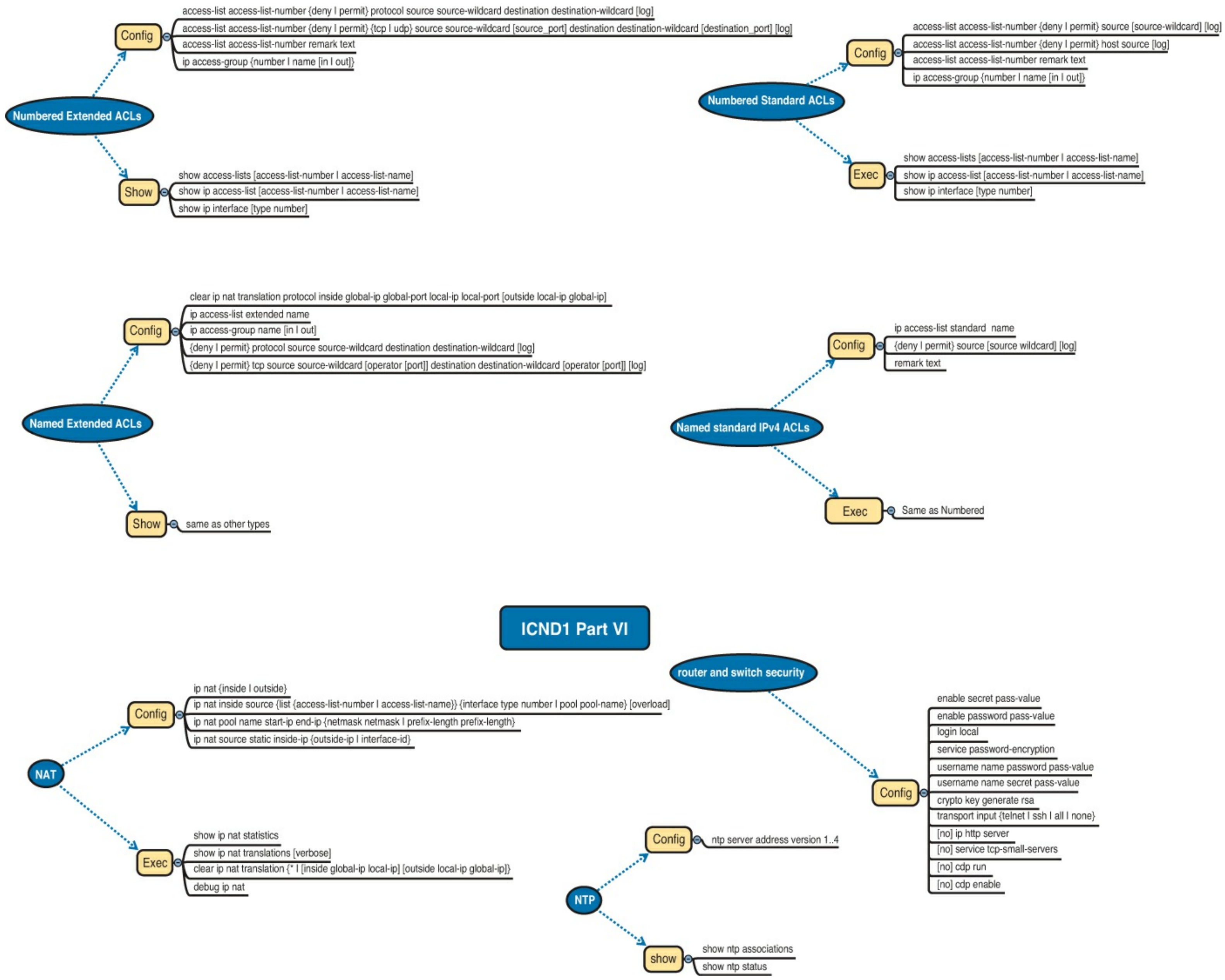

Add New VLSM Subnet
Given
Existing Subnets
Existing masks
Mask of New Subnet
Process
Calculate address ranges of existing subnets
Look for Holes to match new subnet
Result
New Subnet's Subnet ID and Mask


Find Best Summary
Given
Existing Routes w/ Subnet ID/mask
Process
Calculate address ranges of existing subnets
Shorter and shorter /P
Calculate range for one larger subnet/P
Result
Subnet ID/Mask for best summary

ICND1 Part V

Part VI Review Mind Map Solutions

Figure O-6. Part V Review Mind Map Solution



```
access-list access-list-number {deny I permit} protocol source source-wildcard destination destination-wildcard [log]
access-list access-list-number {deny I permit} {tcp I udp} source source-wildcard [source_port] destination destination-wildcard [destination_port] [log]
access-list access-list-number remark text
ip access-group {number I name [in I out]}
show access-lists [access-list-number I access-list-name]
show ip access-list [access-list-number I access-list-name]
show ip interface [type number]
```

```
access-list access-list-number {deny I permit} source [source-wildcard] [log]
access-list access-list-number {deny I permit} host source [log]
access-list access-list-number remark text
ip access-group {number I name [in I out]}
show access-lists [access-list-number I access-list-name]
show ip access-list [access-list-number I access-list-name]
show ip interface [type number]
```

```
clear ip nat translation protocol inside global-ip global-port local-ip local-port [outside local-ip global-ip]
ip access-list extended name
ip access-group name [in I out]
{deny I permit} protocol source source-wildcard destination destination-wildcard [log]
{deny I permit} tcp source source-wildcard [operator [port]] destination destination-wildcard [operator [port]] [log]
same as other types
```

```
ip access-list standard  name
{deny I permit} source [source wildcard] [log]
remark text
Same as Numbered
```

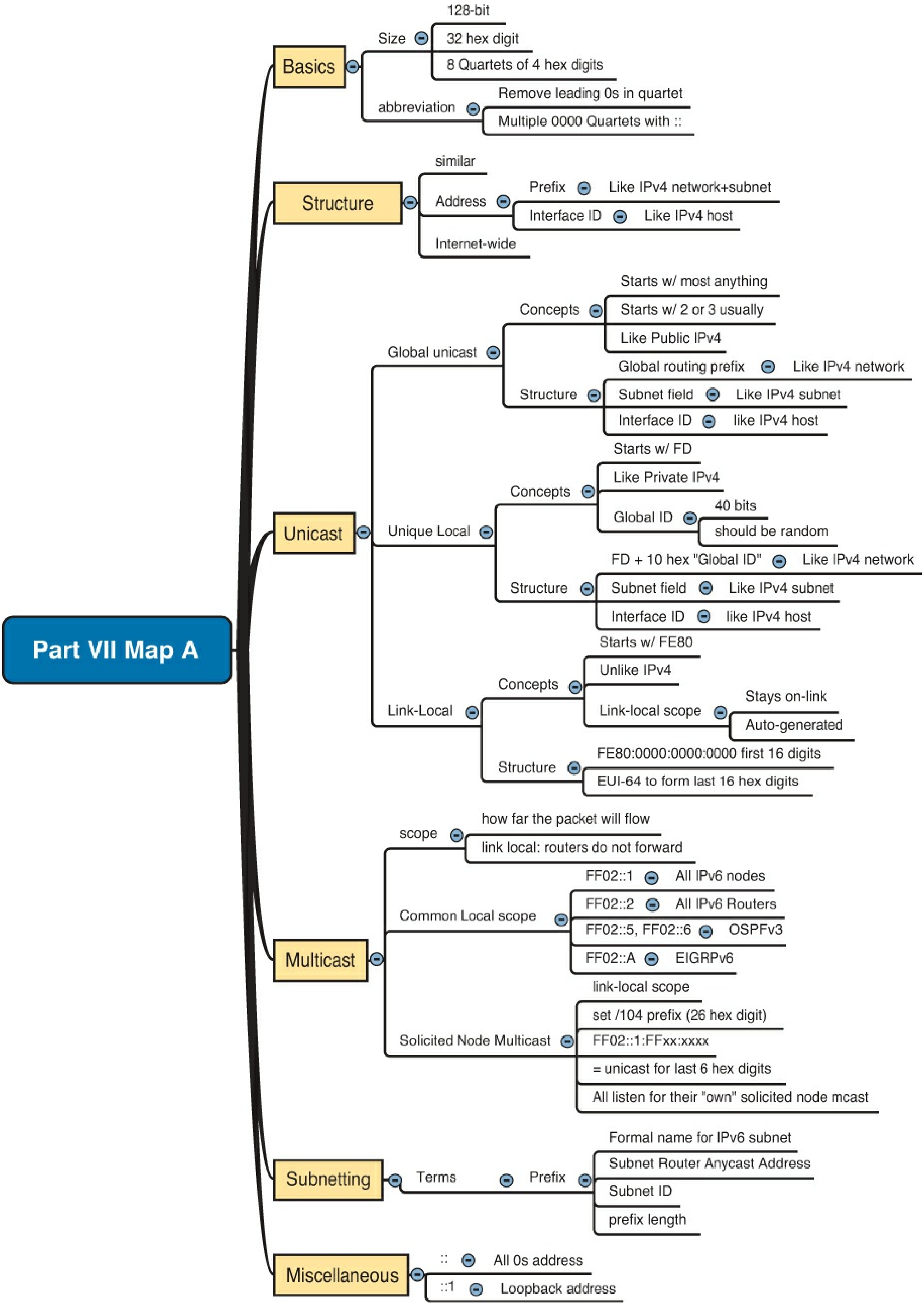
```
ip nat {inside I outside}
ip nat inside source {list {access-list-number I access-list-name}} {interface type number I pool pool-name} [overload]
ip nat pool name start-ip end-ip {netmask netmask I prefix-length prefix-length}
ip nat source static inside-ip {outside-ip I interface-id}
show ip nat statistics
show ip nat translations [verbose]
clear ip nat translation {* I [inside global-ip local-ip] [outside local-ip global-ip]}
debug ip nat
```

```
enable secret pass-value
enable password pass-value
login local
service password-encryption
username name password pass-value
username name secret pass-value
crypto key generate rsa
transport input {telnet I ssh I all I none}
[no] ip http server
[no] service tcp-small-servers
[no] cdp run
[no] cdp enable
```

```
ntp server address version 1..4
show ntp associations
show ntp status
```

Figure O-7. Part VI Review Mind Map Solution

Part VII Review Mind Map Solutions


Part VII Map A
Basics
Size
128-bit
32 hex digit
8 Quartets of 4 hex digits
abbreviation
Remove leading 0s in quartet
Multiple 0000 Quartets with ::
Structure
similar
Address
Prefix
Like IPv4 network+subnet
Interface ID
Like IPv4 host
Internet-wide
Unicast
Global unicast
Concepts
Starts w/ most anything
Starts w/ 2 or 3 usually
Like Public IPv4
Structure
Global routing prefix
Like IPv4 network
Subnet field
Like IPv4 subnet
Interface ID
like IPv4 host
Unique Local
Concepts
Starts w/ FD
Like Private IPv4
Global ID
40 bits
should be random
Structure
FD + 10 hex "Global ID"
Like IPv4 network
Subnet field
Like IPv4 subnet
Interface ID
like IPv4 host
Link-Local
Concepts
Starts w/ FE80
Unlike IPv4
Link-local scope
Stays on-link
Auto-generated
Structure
FE80:0000:0000:0000 first 16 digits
EUI-64 to form last 16 hex digits
Multicast
scope
how far the packet will flow
link local: routers do not forward
Common Local scope
FF02::1
All IPv6 nodes
FF02::2
All IPv6 Routers
FF02::5, FF02::6
OSPFv3
FF02::A
EIGRPv6
Solicited Node Multicast
link-local scope
set /104 prefix (26 hex digit)
FF02::1:FFxx:xxxx
= unicast for last 6 hex digits
All listen for their "own" solicited node mcast
Subnetting
Terms
Prefix
Formal name for IPv6 subnet
Subnet Router Anycast Address
Subnet ID
prefix length
Miscellaneous
::
All 0s address
::1
Loopback address

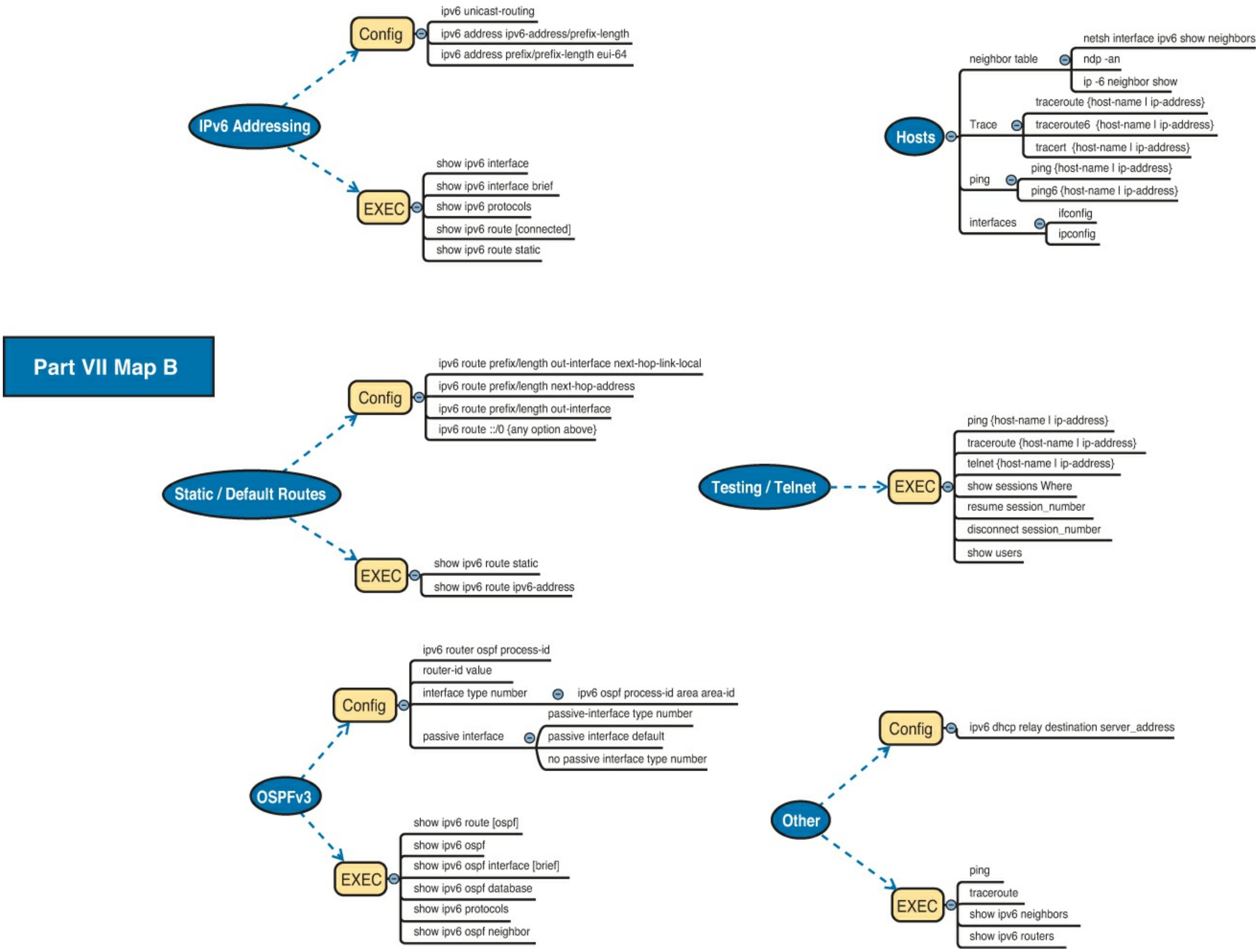
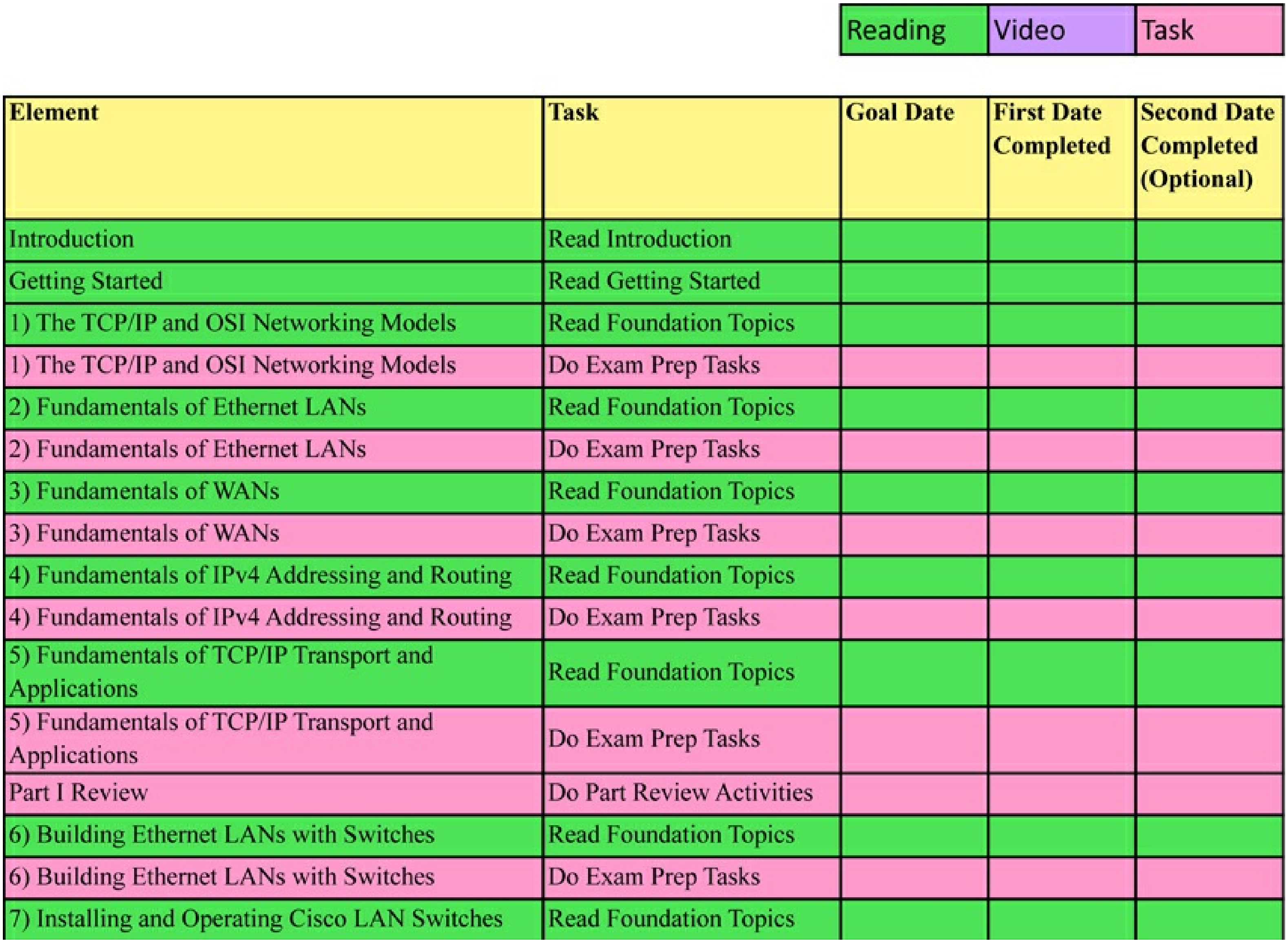

Part VII Map B
IPv6 Addressing
Config
ipv6 unicast-routing
ipv6 address ipv6-address/prefix-length
ipv6 address prefix/prefix-length eui-64
EXEC
show ipv6 interface
show ipv6 interface brief
show ipv6 protocols
show ipv6 route [connected]
show ipv6 route static
Hosts
neighbor table
netsh interface ipv6 show neighbors
ndp -an
ip -6 neighbor show
Trace
traceroute {host-name I ip-address}
traceroute6 {host-name I ip-address}
tracert {host-name I ip-address}
ping
ping {host-name I ip-address}
ping6 {host-name I ip-address}
interfaces
ifconfig
ipconfig
Static / Default Routes
Config
ipv6 route prefix/length out-interface next-hop-link-local
ipv6 route prefix/length next-hop-address
ipv6 route prefix/length out-interface
ipv6 route ::/0 {any option above}
EXEC
show ipv6 route static
show ipv6 route ipv6-address
Testing / Telnet
EXEC
ping {host-name I ip-address}
traceroute {host-name I ip-address}
telnet {host-name I ip-address}
show sessions Where
resume session_number
disconnect session_number
show users
OSPFv3
Config
ipv6 router ospf process-id
router-id value
interface type number
ipv6 ospf process-id area area-id
passive interface
passive-interface type number
passive interface default
no passive interface type number
EXEC
show ipv6 route [ospf]
show ipv6 ospf
show ipv6 ospf interface [brief]
show ipv6 ospf database
show ipv6 protocols
show ipv6 ospf neighbor
Other
Config
ipv6 dhcp relay destination server_address
EXEC
ping
traceroute
show ipv6 neighbors
show ipv6 routers

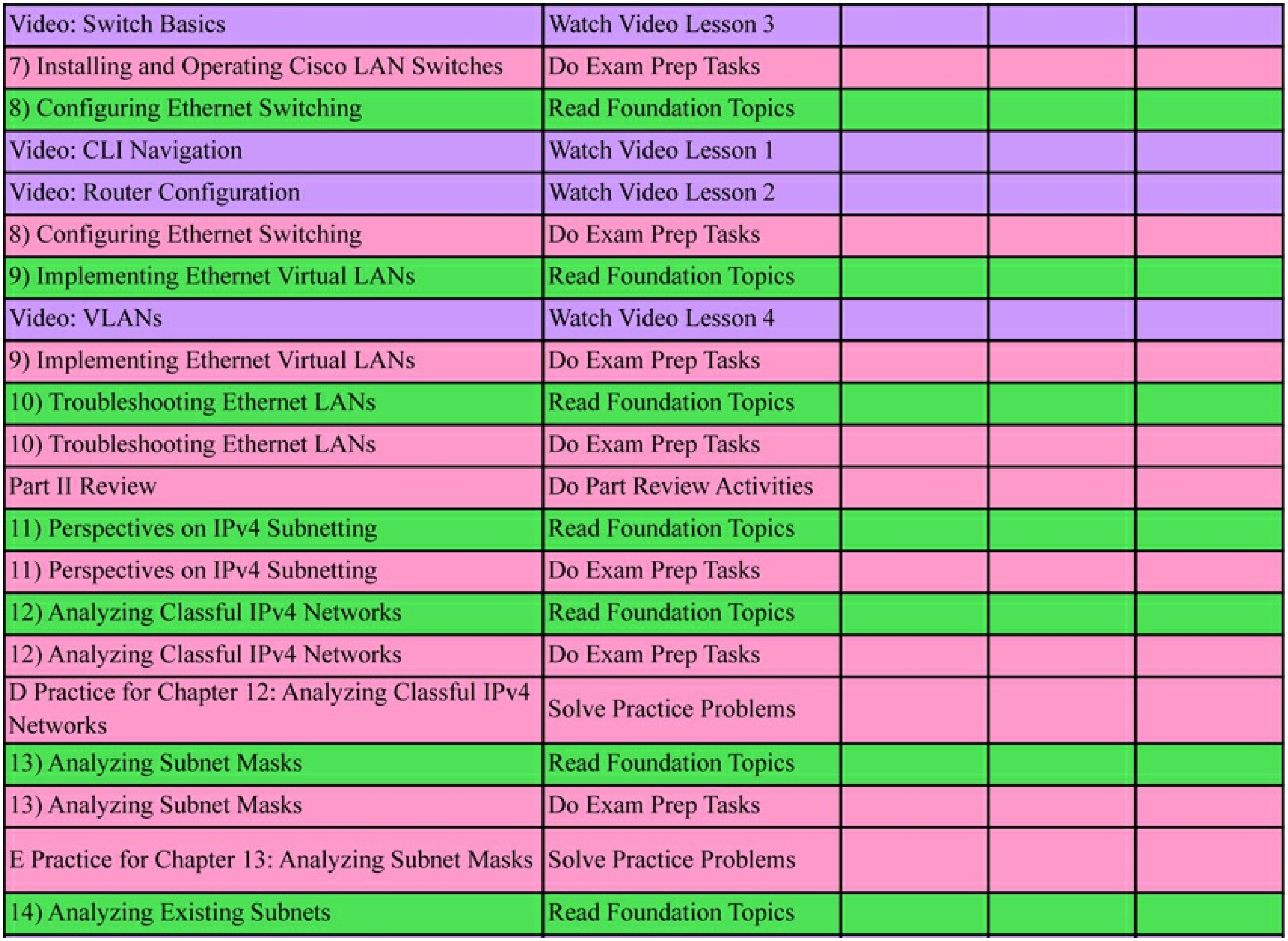
Figure O-9. Part VII Review Mind Map Solution B

Appendix P. Study Planner



Reading	Video	Task

Element	Task	Goal Date	First Date Completed	Second Date Completed (Optional)
Introduction	Read Introduction			
Getting Started	Read Getting Started			
1) The TCP/IP and OSI Networking Models	Read Foundation Topics			
1) The TCP/IP and OSI Networking Models	Do Exam Prep Tasks			
2) Fundamentals of Ethernet LANs	Read Foundation Topics			
2) Fundamentals of Ethernet LANs	Do Exam Prep Tasks			
3) Fundamentals of WANs	Read Foundation Topics			
3) Fundamentals of WANs	Do Exam Prep Tasks			
4) Fundamentals of IPv4 Addressing and Routing	Read Foundation Topics			
4) Fundamentals of IPv4 Addressing and Routing	Do Exam Prep Tasks			
5) Fundamentals of TCP/IP Transport and Applications	Read Foundation Topics			
5) Fundamentals of TCP/IP Transport and Applications	Do Exam Prep Tasks			
Part I Review	Do Part Review Activities			
6) Building Ethernet LANs with Switches	Read Foundation Topics			
6) Building Ethernet LANs with Switches	Do Exam Prep Tasks			
7) Installing and Operating Cisco LAN Switches	Read Foundation Topics			



Video: Switch Basics	Watch Video Lesson 3			
7) Installing and Operating Cisco LAN Switches	Do Exam Prep Tasks			
8) Configuring Ethernet Switching	Read Foundation Topics			
Video: CLI Navigation	Watch Video Lesson 1			
Video: Router Configuration	Watch Video Lesson 2			
8) Configuring Ethernet Switching	Do Exam Prep Tasks			
9) Implementing Ethernet Virtual LANs	Read Foundation Topics			
Video: VLANs	Watch Video Lesson 4			
9) Implementing Ethernet Virtual LANs	Do Exam Prep Tasks			
10) Troubleshooting Ethernet LANs	Read Foundation Topics			
10) Troubleshooting Ethernet LANs	Do Exam Prep Tasks			
Part II Review	Do Part Review Activities			
11) Perspectives on IPv4 Subnetting	Read Foundation Topics			
11) Perspectives on IPv4 Subnetting	Do Exam Prep Tasks			
12) Analyzing Classful IPv4 Networks	Read Foundation Topics			
12) Analyzing Classful IPv4 Networks	Do Exam Prep Tasks			
D Practice for Chapter 12: Analyzing Classful IPv4 Networks	Solve Practice Problems			
13) Analyzing Subnet Masks	Read Foundation Topics			
13) Analyzing Subnet Masks	Do Exam Prep Tasks			
E Practice for Chapter 13: Analyzing Subnet Masks	Solve Practice Problems			
14) Analyzing Existing Subnets	Read Foundation Topics			

Video: Finding the Subnet Number 1	Watch Video Lesson 5			
Video: Finding the Subnet Number 2	Watch Video Lesson 6			
Video: Finding the Subnet Number 3	Watch Video Lesson 7			
Video: Finding the Range of Addresses 1	Watch Video Lesson 8			
Video: Finding the Range of Addresses 2	Watch Video Lesson 9			
Video: Finding the Range of Addresses 3	Watch Video Lesson 10			
14) Analyzing Existing Subnets	Do Exam Prep Tasks			
F Practice for Chapter 14: Analyzing Existing Subnets	Solve Practice Problems			
Part III Review	Do Part Review Activities			
15) Operating Cisco Routers	Read Foundation Topics			
15) Operating Cisco Routers	Do Exam Prep Tasks			
16) Configuring IPv4 Addresses and Routes	Read Foundation Topics			
16) Configuring IPv4 Addresses and Routes	Do Exam Prep Tasks			
17) Learning IPv4 Routes with OSPFv2	Read Foundation Topics			
17) Learning IPv4 Routes with OSPFv2	Do Exam Prep Tasks			
18) Configuring and Verifying Host Connectivity	Read Foundation Topics			
18) Configuring and Verifying Host Connectivity	Do Exam Prep Tasks			
Part IV Review	Do Part Review Activities			
19) Subnet Design	Read Foundation Topics			
Video: Finding All Subnet IDs with Less Than 8 Subnet Bits	Watch Video Lesson 11			

Video: Finding All Subnet IDs with More Than 8 Subnet Bits	Watch Video Lesson 12			
19) Subnet Design	Do Exam Prep Tasks			
G Practice for Chapter 19: Subnet Design	Solve Practice Problems			
20) Variable-Length Subnet Masks	Read Foundation Topics			
20) Variable-Length Subnet Masks	Do Exam Prep Tasks			
H Practice for Chapter 20: Variable-Length Subnet Masks	Solve Practice Problems			
21) Route Summarization	Read Foundation Topics			
21) Route Summarization	Do Exam Prep Tasks			
I: Practice for Chapter 21: Route Summarization	Solve Practice Problems			
Part V Review	Do Part Review Activities			
22) Basic IPv4 Access Control Lists	Read Foundation Topics			
22) Basic IPv4 Access Control Lists	Do Exam Prep Tasks			
J: Practice for Chapter 22: Basic IPv4 Access Control Lists	Solve Practice Problems			
23) Advanced IPv4 ACLs and Device Security	Read Foundation Topics			
23) Advanced IPv4 ACLs and Device Security	Do Exam Prep Tasks			
24) Network Address Translation	Read Foundation Topics			
24) Network Address Translation	Do Exam Prep Tasks			
Part VI Review	Do Part Review Activities			
25) Fundamentals of IP Version 6	Read Foundation Topics			
25) Fundamentals of IP Version 6	Do Exam Prep Tasks			
K: Practice for Chapter 25: Fundamentals of IP Version 6	Solve Practice Problems			
26) IPv6 Addressing and Subnetting	Read Foundation Topics			
26) IPv6 Addressing and Subnetting	Do Exam Prep Tasks			
27) Implementing IPv6 Addressing on Routers	Read Foundation Topics			
27) Implementing IPv6 Addressing on Routers	Do Exam Prep Tasks			
L: Practice for Chapter 27: Implementing IPv6 Addressing on Routers	Solve Practice Problems			
28) Implementing IPv6 Addressing on Hosts	Read Foundation Topics			
28) Implementing IPv6 Addressing on Hosts	Do Exam Prep Tasks			
29) Implementing IPv6 Routing	Read Foundation Topics			
29) Implementing IPv6 Routing	Do Exam Prep Tasks			
Part VII Review	Do Part Review Activities			
30) Final Review	Practice Subnetting for Speed			
30) Final Review	Take Practice Exams			
30) Final Review	Review Questions			
30) Final Review	Practice CLI Skills			

In addition to the wealth of updated content, this new edition includes a series of free hands-on exercises to help you master several real-world configuration and troubleshooting activities. These exercises can be performed on the CCENT/CCNA ICND1 100-101 Network Simulator Lite software included for free on the DVD that accompanies this book. This software, which simulates the experience of working on actual Cisco routers and switches, contains the following 13 free lab exercises: **1.** Configuring IP Addresses I Skill Builder Lab **2.** Configuring IP Addresses II Skill Builder Lab **3.** Connected Routes Skill Builder Lab

4. Static Routes I Skill Builder Lab

5. Static Routes II Skill Builder Lab

6. Subnet Zero I Skill Builder Lab

7. Loopback Interfaces Skill Builder Lab

8. Subnet ID Calculation I Subnetting Exercise Lab **9.** IP Address Rejection I Subnetting Exercise Lab **10.** IP Route Selection I Subnetting Exercise Lab **11.** Subnetting and Addressing I Configuration Scenario **12.** Static Routing I Configuration Scenario

13. Network Discovery II Troubleshooting Scenario If you are interested in exploring more hands-on labs and practicing configuration and troubleshooting with more router and switch commands, check out our full simulator product offerings at http://www.pearsonitcertification.com/networksimulator.

CCENT ICND1 Network Simulator Lite minimum system requirements:

- Microsoft Windows XP (SP3), Windows Vista (32-bit/64-bit) with SP1, Windows 7 (32-bit/64-bit) or Windows 8 (32-bit/64-bit, x86 processors), Mac OS X 10.6, 10.7, or 10.8
- Intel Pentium III 1GHz or faster processor ■ 512 MB RAM (1GB recommended) ■ 1 GB hard disk space ■ 32-bit color depth at 1024x768 resolution ■ Adobe Acrobat Reader version 8 and above

Other applications installed during installation:

- Adobe AIR 3.6.0
- Captive JRE 6

Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide is part of a recommended learning path from Cisco that includes simulation and hands-on training from authorized Cisco Learning Partners and self-study products from Cisco Press. To find out more about instructor-led training, e-learning, and hands-on instruction offered by authorized Cisco Learning Partners worldwide, please visit www.cisco.com/go/authorizedtraining.

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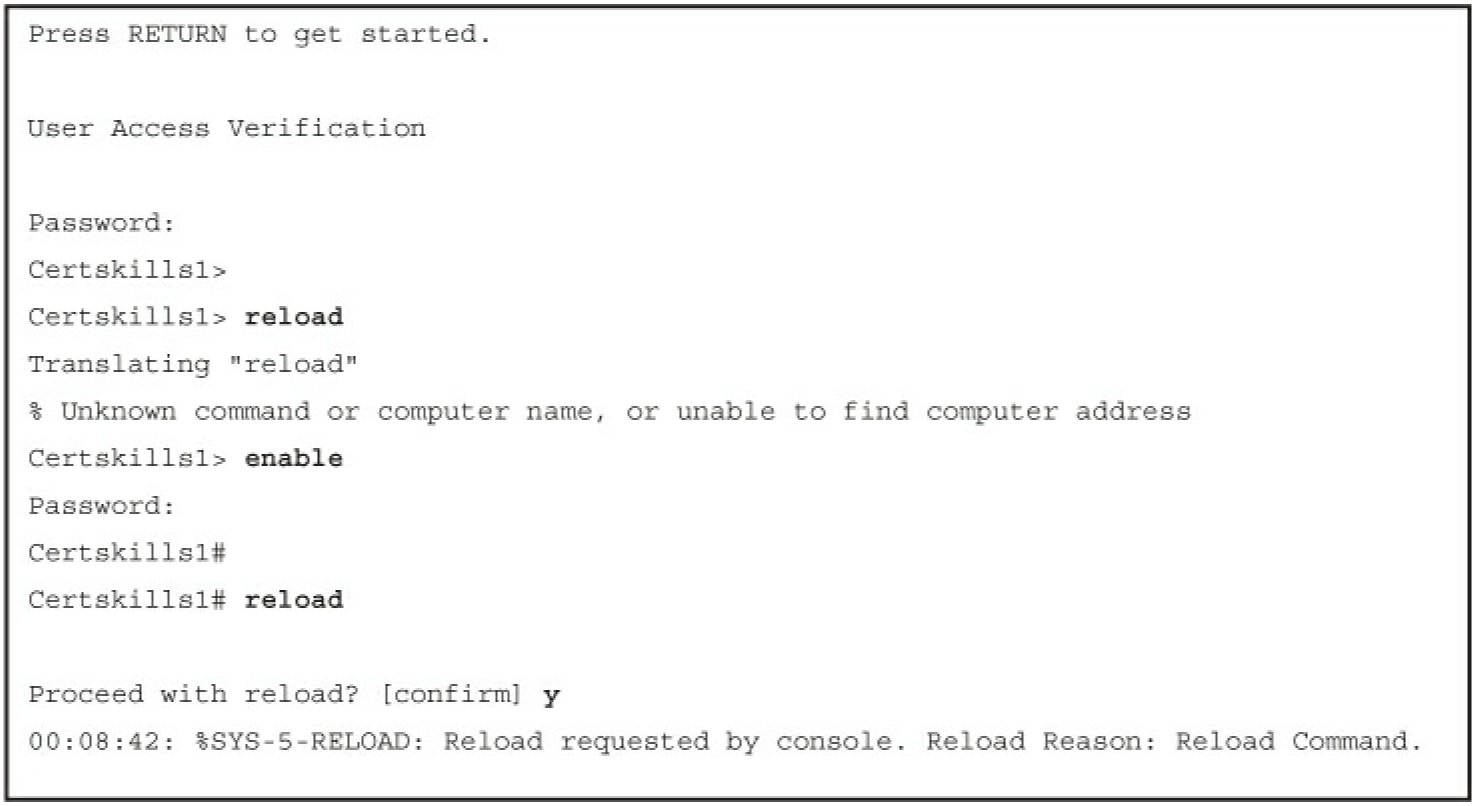


```
Press RETURN to get started.


User Access Verification


Password:
Certskills1>
Certskills1> reload
Translating "reload"
% Unknown command or computer name, or unable to find computer address
Certskills1> enable
Password:
Certskills1#
Certskills1# reload

Proceed with reload? [confirm] y
00:08:42: %SYS-5-RELOAD: Reload requested by console. Reload Reason: Reload Command.
```

```
Switch# configure terminal
Switch(config)# hostname Fred
Fred(config)# line console 0
Fred(config-line)# password hope
Fred(config-line)# interface FastEthernet 0/1
Fred(config-if)# speed 100
Fred(config-if)# exit
Fred(config)#
```

```
! Step 1 next (two commands)
!
hannah# show running-config
! (lines omitted)
hostname hannah
! (rest of lines omitted)

hannah# show startup-config
! (lines omitted)
hostname hannah
! (rest of lines omitted)
! Step 2 next. Notice that the command prompt changes immediately after
! the hostname command.
hannah# configure terminal
hannah(config)# hostname jessie
jessie(config)# exit
! Step 3 next (two commands)
!
jessie# show running-config
! (lines omitted)
hostname jessie
! (rest of lines omitted - notice that the running configuration reflects the
!  changed hostname)
jessie# show startup-config
! (lines omitted)
hostname hannah
! (rest of lines omitted - notice that the changed configuration is not
! shown in the startup config)
```

```
--- System Configuration Dialog ---


Would you like to enter the initial configuration dialog? [yes/no]: no


Switch>
```

```
SW1# show version
Cisco IOS Software, C2960 Software (C2960-LANBASEK9-M), Version 15.0(1)SE3, RELEASE
SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2012 by Cisco Systems, Inc.
Compiled Wed 30-May-12 14:26 by prod_rel_team

ROM: Bootstrap program is C2960 boot loader
BOOTLDR: C2960 Boot Loader (C2960-HBOOT-M) Version 12.2(44)SE5, RELEASE SOFTWARE (fc1)

SW1 uptime is 2 days, 22 hours, 2 minutes
System returned to ROM by power-on
System image file is "flash:c2960-lanbasek9-mz.150-1.SE3.bin"



This product contains cryptographic features and is subject to United
States and local country laws governing import, export, transfer and
use…
! Lines omitted for brevity

cisco WS-C2960-24TT-L (PowerPC405) processor (revision P0) with 65536K bytes of
  memory.
Processor board ID FCQ1621X6QC
Last reset from power-on
1 Virtual Ethernet interface
24 FastEthernet interfaces
2 Gigabit Ethernet interfaces
The password-recovery mechanism is enabled.

64K bytes of flash-simulated non-volatile configuration memory.
Base ethernet MAC Address        : 18:33:9D:7B:13:80
Motherboard assembly number      : 73-11473-11
Power supply part number         : 341-0097-03
Motherboard serial number        : FCQ162103ZL
Power supply serial number       : ALD1619B37W
Model revision number            : P0
Motherboard revision number      : A0
Model number                     : WS-C2960-24TT-L
System serial number             : FCQ1621X6QC
Top Assembly Part Number         : 800-29859-06
Top Assembly Revision Number     : C0
Version ID                       : V10
```

```
CLEI Code Number                : COMCX00ARB
Hardware Board Revision Number  : 0x01



Switch Ports Model              SW Version            SW Image
------ ----- -----              ----------            ----------
*    1 26    WS-C2960-24TT-L    15.0(1)SE3            C2960-LANBASEK9-M



Configuration register is 0xF
```

```
Emma# show running-config
!
Building configuration...

Current configuration : 1333 bytes
!
version 12.2
!
hostname Emma
!
enable secret 5 $1$YXRN$11zOe1Lb0Lv/nHyTquobd.
!
spanning-tree mode pvst
spanning-tree extend system-id
!
interface FastEthernet0/1
!
interface FastEthernet0/2
!
! Several lines have been omitted here - in particular, lines for FastEthernet
! interfaces 0/3 through 0/23.
!
interface FastEthernet0/24
!
interface GigabitEthernet0/1
!
interface GigabitEthernet0/2
!
interface Vlan1
 no ip address
 no ip route-cache
!
!
line con 0
 password faith
 login
!
line vty 0 4
 password love
 login
!
line vty 5 15
 password love
 login
```

```
Emma# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Emma(config)# line vty 0 15
! Step 1's key command happens next
Emma(config-line)# login local
Emma(config-line)# exit
!
! Step 2's command happens next
Emma(config)# username wendell password odom
Emma(config)# username chris password youdaman
!
! Step 3's two commands happen next
Emma(config)# ip domain-name example.com
Emma(config)# crypto key generate rsa
The name for the keys will be: Emma.example.com
Choose the size of the key modulus in the range of 360 to 2048 for your
  General Purpose Keys. Choosing a key modulus greater than 512 may take
  a few minutes.

How many bits in the modulus [512]: 1024
% Generating 1024 bit RSA keys, keys will be non-exportable...
[OK] (elapsed time was 4 seconds)

Emma(config)# ip ssh version 2
Emma(config)# ^Z
Emma#
```

```
Emma# show ip ssh
SSH Enabled - version 2.0
Authentication timeout: 120 secs; Authentication retries: 3
Minimum expected Diffie Hellman key size : 1024 bits
IOS Keys in SECSH format(ssh-rsa, base64 encoded):
ssh-rsa AAAAB3NzaC1yc2EAAAADAQABAAAAgQC+/mp2iaeaGwjqkIgLNH+lN/04LTc2u6qHVHHv3hoq
/DDBd9vABNnJGsq8z0Hm9HcrSudC20N/cCuEb4x5+T9rvNkUeAqwEEoJALpdiWVOpBliomhPysvJi+m4
wI16AH31KI+GFCZv1AIjZSYHQEbvdCEqsYezAeKnPhvzTrUqaQ==
Emma# show ssh
Connection Version Mode Encryption  Hmac         State                 Username
0          2.0     IN   aes128-cbc  hmac-sha1    Session started       wendell
0          2.0     OUT  aes128-cbc  hmac-sha1    Session started       wendell
%No SSHv1 server connections running.
```

```
Switch3# show running-config | begin line vty
line vty 0 4
 password cisco
 login
line vty 5 15
 password cisco
 login

Switch3# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Switch3(config)# service password-encryption
Switch3(config)# ^Z

Switch3# show running-config | begin line vty
line vty 0 4
 password 7 070C285F4D06
 login
line vty 5 15
 password 7 070C285F4D06
 login
end
```

```
Switch3# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Switch3(config)# no service password-encryption
Switch3(config)# ^Z
Switch3# show running-config | section vty
line vty 0 4
 password 7 070C285F4D06
 login
line vty 5 15
 password 7 070C285F4D06
 login
end
Switch3# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Switch3(config)# line vty 0 4
Switch3(config-line)# password cisco
Switch3(config-line)# ^Z

Switch3# show running-config | begin line vty
line vty 0 4
 password cisco
 login
line vty 5 15
 password 7 070C285F4D06
 login
end
```

```
Switch3(config)# enable secret ?
  0      Specifies an UNENCRYPTED password will follow
  5      Specifies an ENCRYPTED secret will follow
  LINE   The UNENCRYPTED (cleartext) 'enable' secret
  level  Set exec level password

Switch3(config)# enable secret fred
Switch3(config)# ^Z
Switch3# show running-config | include enable secret

enable secret 5 $1$ZGMA$e8cmvkz4UjiJhVp7.maLE1

Switch3# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Switch3(config)# no enable secret
Switch3(config)# ^Z
```

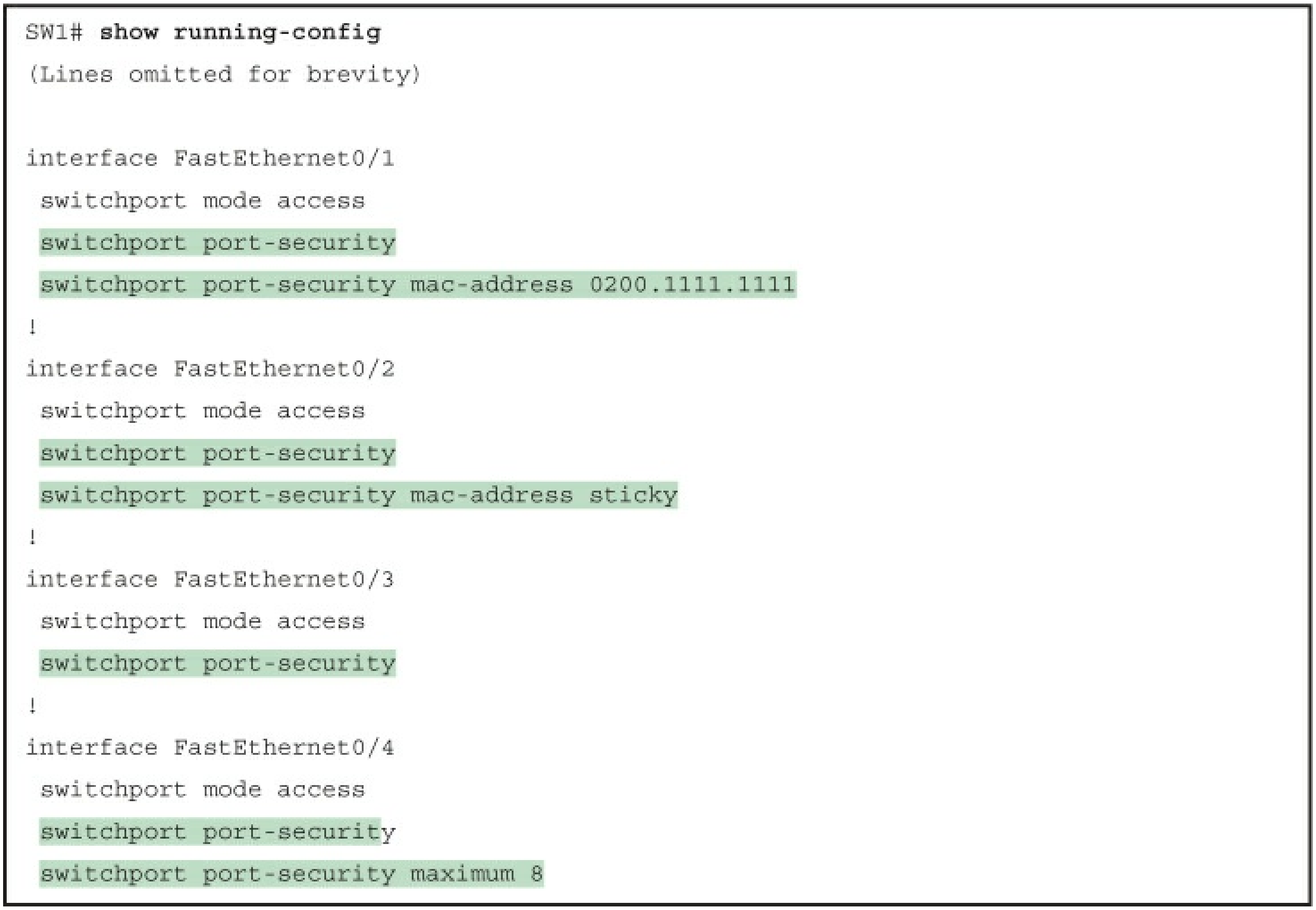
```
! Below, the three banners are created in configuration mode. Note that any
! delimiter can be used, as long as the character is not part of the message
! text.

SW1(config)# banner #
Enter TEXT message.  End with the character '#'.
(MOTD) Switch down for maintenance at 11PM Today #
SW1(config)# banner login #
Enter TEXT message.  End with the character '#'.
(Login) Unauthorized Access Prohibited!!!!
#
SW1(config)# banner exec Z
Enter TEXT message.  End with the character 'Z'.
(Exec) Company picnic at the park on Saturday
 Don’t tell outsiders!
Z
SW1(config)# end

! Below, the user of this router quits the console connection, and logs back in,
! seeing the motd and login banners, then the password prompt, and then the
! exec banner.
SW1#quit

SW1 con0 is now available

Press RETURN to get started.

(MOTD) Switch down for maintenance at 11PM Today
(Login) Unauthorized Access Prohibited!!!!

User Access Verification

Username: fred
Password:
(Exec) Company picnic at the park on Saturday
don’t tell outsiders!
SW1>
```

```
Emma# configure terminal
Emma(config)# interface vlan 1
Emma(config-if)# ip address 192.168.1.200 255.255.255.0
Emma(config-if)# no shutdown
00:25:07: %LINK-3-UPDOWN: Interface Vlan1, changed state to up
00:25:08: %LINEPROTO-5-UPDOWN: Line protocol on Interface Vlan1, changed
  state to up
Emma(config-if)# exit
Emma(config)# ip default-gateway 192.168.1.1
```

```
Emma# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Emma(config)# interface vlan 1
Emma(config-if)# ip address dhcp
Emma(config-if)# no shutdown
Emma(config-if)# ^Z
Emma#
00:38:20: %LINK-3-UPDOWN: Interface Vlan1, changed state to up
00:38:21: %LINEPROTO-5-UPDOWN: Line protocol on Interface Vlan1, changed state to up
```

```
Emma# show dhcp lease
Temp IP addr: 192.168.1.101  for peer on Interface: Vlan1
Temp  sub net mask: 255.255.255.0
   DHCP Lease server: 192.168.1.1, state: 3 Bound
   DHCP transaction id: 1966
   Lease: 86400 secs,  Renewal: 43200 secs,  Rebind: 75600 secs
Temp default-gateway addr: 192.168.1.1
   Next timer fires after: 11:59:45
   Retry count: 0   Client-ID: cisco-0019.e86a.6fc0-Vl1
   Hostname: Emma
Emma# show interfaces vlan 1
Vlan1 is up, line protocol is up
  Hardware is EtherSVI, address is 0019.e86a.6fc0 (bia 0019.e86a.6fc0)
  Internet address is 192.168.1.101/24
  MTU 1500 bytes, BW 1000000 Kbit, DLY 10 usec,
     reliability 255/255, txload 1/255, rxload 1/255
! lines omitted for brevity
Emma# show ip default-gateway
192.168.1.1
```

```
Emma# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Emma(config)# interface FastEthernet 0/1
Emma(config-if)# duplex full
Emma(config-if)# speed 100
Emma(config-if)# description Server1 connects here
Emma(config-if)# exit
Emma(config)# interface range FastEthernet 0/11 - 20
Emma(config-if-range)# description end-users connect_here
Emma(config-if-range)# ^Z
Emma#
Emma# show interfaces status
Port      Name               Status       Vlan       Duplex  Speed Type
Fa0/1     Server1 connects h notconnect   1            full    100 10/100BaseTX
Fa0/2                        notconnect   1            auto   auto 10/100BaseTX
Fa0/3                        notconnect   1            auto   auto 10/100BaseTX
Fa0/4                        connected    1          a-full  a-100 10/100BaseTX
Fa0/5                        notconnect   1            auto   auto 10/100BaseTX
Fa0/6                        connected    1          a-full  a-100 10/100BaseTX
Fa0/7                        notconnect   1            auto   auto 10/100BaseTX
Fa0/8                        notconnect   1            auto   auto 10/100BaseTX
Fa0/9                        notconnect   1            auto   auto 10/100BaseTX
Fa0/10                       notconnect   1            auto   auto 10/100BaseTX
Fa0/11    end-users connect  notconnect   1            auto   auto 10/100BaseTX
Fa0/12    end-users connect  notconnect   1            auto   auto 10/100BaseTX
Fa0/13    end-users connect  notconnect   1            auto   auto 10/100BaseTX
Fa0/14    end-users connect  notconnect   1            auto   auto 10/100BaseTX
Fa0/15    end-users connect  notconnect   1            auto   auto 10/100BaseTX
Fa0/16    end-users connect  notconnect   1            auto   auto 10/100BaseTX
Fa0/17    end-users connect  notconnect   1            auto   auto 10/100BaseTX
Fa0/18    end-users connect  notconnect   1            auto   auto 10/100BaseTX
Fa0/19    end-users connect  notconnect   1            auto   auto 10/100BaseTX
Fa0/20    end-users connect  notconnect   1            auto   auto 10/100BaseTX
Fa0/21                       notconnect   1            auto   auto 10/100BaseTX
Fa0/22                       notconnect   1            auto   auto 10/100BaseTX
Fa0/23                       notconnect   1            auto   auto 10/100BaseTX
Fa0/24                       notconnect   1            auto   auto 10/100BaseTX
Gi0/1                        notconnect   1            auto   auto 10/100/1000BaseTX
Gi0/2                        notconnect   1            auto   auto 10/100/1000BaseTX
```



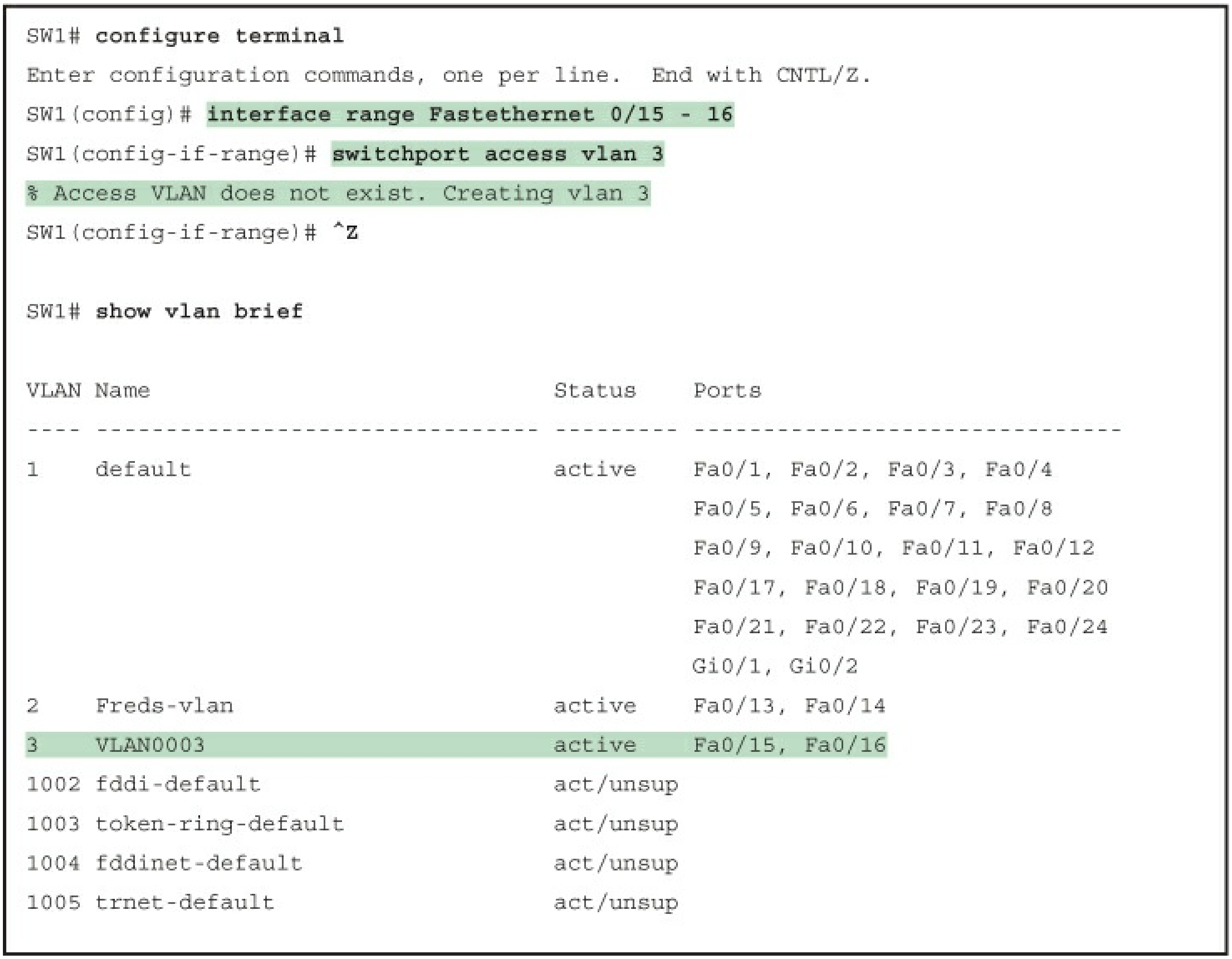
```
SW1# show running-config
(Lines omitted for brevity)

interface FastEthernet0/1
 switchport mode access
 switchport port-security
 switchport port-security mac-address 0200.1111.1111
!
interface FastEthernet0/2
 switchport mode access
 switchport port-security
 switchport port-security mac-address sticky
!
interface FastEthernet0/3
 switchport mode access
 switchport port-security
!
interface FastEthernet0/4
 switchport mode access
 switchport port-security
 switchport port-security maximum 8
```

```
SW1# show port-security interface fastEthernet 0/1
Port Security              : Enabled
Port Status                : Secure-shutdown
Violation Mode             : Shutdown
Aging Time                 : 0 mins
Aging Type                 : Absolute
SecureStatic Address Aging : Disabled
Maximum MAC Addresses      : 1
Total MAC Addresses        : 1
Configured MAC Addresses   : 1
Sticky MAC Addresses       : 0
Last Source Address:Vlan   : 0013.197b.5004:1
Security Violation Count   : 1

SW1# show port-security interface fastEthernet 0/2
Port Security              : Enabled
Port Status                : Secure-up
Violation Mode             : Shutdown
Aging Time                 : 0 mins
Aging Type                 : Absolute
SecureStatic Address Aging : Disabled
Maximum MAC Addresses      : 1
Total MAC Addresses        : 1
Configured MAC Addresses   : 1
Sticky MAC Addresses       : 1
Last Source Address:Vlan   : 0200.2222.2222:1
Security Violation Count   : 0

SW1# show running-config
(Lines omitted for brevity)
interface FastEthernet0/2
 switchport mode access
 switchport port-security
 switchport port-security mac-address sticky
 switchport port-security mac-address sticky 0200.2222.2222
```

```
VLAN Name                             Status    Ports
---- -------------------------------- --------- -------------------------------
1    default                          active    Fa0/1, Fa0/2, Fa0/3, Fa0/4
                                                Fa0/5, Fa0/6, Fa0/7, Fa0/8
                                                Fa0/9, Fa0/10, Fa0/11, Fa0/12
                                                Fa0/13, Fa0/14, Fa0/15, Fa0/16
                                                Fa0/17, Fa0/18, Fa0/19, Fa0/20
                                                Fa0/21, Fa0/22, Fa0/23, Fa0/24
                                                Gi0/1, Gi0/2
1002 fddi-default                     act/unsup
1003 token-ring-default               act/unsup
1004 fddinet-default                  act/unsup
1005 trnet-default                    act/unsup
! Above, VLANs 2 and 3 do not yet exist. Below, VLAN 2 is added, with name Freds-vlan,
! with two interfaces assigned to VLAN 2.

SW1# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
SW1(config)# vlan 2
SW1(config-vlan)# name Freds-vlan
SW1(config-vlan)# exit
SW1(config)# interface range fastethernet 0/13 - 14
```

```
SW1(config-if)# switchport access vlan 2
SW1(config-if)# end

! Below, the show running-config command lists the interface subcommands on
! interfaces Fa0/13 and Fa0/14.
SW1# show running-config
! Many lines omitted for brevity
! Early in the output:
vlan 2
 name Freds-vlan
!
! more lines omitted for brevity
interface FastEthernet0/13
 switchport access vlan 2
 switchport mode access
!
interface FastEthernet0/14
 switchport access vlan 2
 switchport mode access
!

SW1# show vlan brief

VLAN Name                             Status    Ports
---- -------------------------------- --------- -------------------------------
1    default                          active    Fa0/1, Fa0/2, Fa0/3, Fa0/4
                                                Fa0/5, Fa0/6, Fa0/7, Fa0/8
                                                Fa0/9, Fa0/10, Fa0/11, Fa0/12
                                                Fa0/15, Fa0/16, Fa0/17, Fa0/18
                                                Fa0/19, Fa0/20, Fa0/21, Fa0/22
                                                Fa0/23, Fa0/24, Gi0/1, Gi0/2
2    Freds-vlan                       active    Fa0/13, Fa0/14
1002 fddi-default                     act/unsup
1003 token-ring-default               act/unsup
1004 fddinet-default                  act/unsup
1005 trnet-default                    act/unsup

SW1# show vlan id 2
VLAN Name                             Status    Ports
---- -------------------------------- --------- -------------------------------
2   Freds-vlan                        active    Fa0/13, Fa0/14
```

```
VLAN Type  SAID       MTU   Parent RingNo BridgeNo Stp  BrdgMode Trans1 Trans2
---- ----- ---------- ----- ------ ------ -------- ---- -------- ------ ------
2    enet  100010     1500  -      -      -        -    -        0      0

Remote SPAN VLAN
----------------
Disabled

Primary Secondary Type              Ports
------- --------- ----------------- ------------------------------------------

```



```
SW1# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
SW1(config)# interface range Fastethernet 0/15 - 16
SW1(config-if-range)# switchport access vlan 3
% Access VLAN does not exist. Creating vlan 3
SW1(config-if-range)# ^Z

SW1# show vlan brief

VLAN Name                             Status    Ports
---- -------------------------------- --------- -------------------------------
1    default                          active    Fa0/1, Fa0/2, Fa0/3, Fa0/4
                                                Fa0/5, Fa0/6, Fa0/7, Fa0/8
                                                Fa0/9, Fa0/10, Fa0/11, Fa0/12
                                                Fa0/17, Fa0/18, Fa0/19, Fa0/20
                                                Fa0/21, Fa0/22, Fa0/23, Fa0/24
                                                Gi0/1, Gi0/2
2    Freds-vlan                       active    Fa0/13, Fa0/14
3    VLAN0003                         active    Fa0/15, Fa0/16
1002 fddi-default                     act/unsup
1003 token-ring-default               act/unsup
1004 fddinet-default                  act/unsup
1005 trnet-default                    act/unsup
```

```
SW1# show interfaces gigabit 0/1 switchport
Name: Gi0/1
Switchport: Enabled
Administrative Mode: dynamic auto
Operational Mode: static access
Administrative Trunking Encapsulation: dot1q
Operational Trunking Encapsulation: native
Negotiation of Trunking: On
Access Mode VLAN: 1 (default)
Trunking Native Mode VLAN: 1 (default)
Administrative Native VLAN tagging: enabled
Voice VLAN: none
Access Mode VLAN: 1 (default)
Trunking Native Mode VLAN: 1 (default)
Administrative Native VLAN tagging: enabled
Voice VLAN: none
Administrative private-vlan host-association: none
Administrative private-vlan mapping: none
Administrative private-vlan trunk native VLAN: none
Administrative private-vlan trunk Native VLAN tagging: enabled
Administrative private-vlan trunk encapsulation: dot1q
Administrative private-vlan trunk normal VLANs: none
Administrative private-vlan trunk private VLANs: none
Operational private-vlan: none
Trunking VLANs Enabled: ALL
Pruning VLANs Enabled: 2-1001
Capture Mode Disabled
Capture VLANs Allowed: ALL

Protected: false
Unknown unicast blocked: disabled
Unknown multicast blocked: disabled
Appliance trust: none

! Note that the next command results in a single empty line of output.
SW1# show interfaces trunk
SW1#
```

```
SW1# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
SW1(config)# interface gigabit 0/1
SW1(config-if)# switchport mode dynamic desirable
SW1(config-if)# ^Z
SW1#
01:43:46: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet0/1, changed
state to down
01:43:49: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet0/1, changed
state to up
SW1# show interfaces gigabit 0/1 switchport
Name: Gi0/1
Switchport: Enabled
Administrative Mode: dynamic desirable
Operational Mode: trunk
Administrative Trunking Encapsulation: dot1q
Operational Trunking Encapsulation: dot1q
Negotiation of Trunking: On
Access Mode VLAN: 1 (default)
Trunking Native Mode VLAN: 1 (default)
! lines omitted for brevity

! The next command formerly listed a single empty line of output; now it lists
! information about the 1 operational trunk.
SW1# show interfaces trunk

Port        Mode         Encapsulation  Status        Native vlan
```

```
Gi0/1       desirable    802.1q         trunking      1

Port        Vlans allowed on trunk
Gi0/1       1-4094

Port        Vlans allowed and active in management domain
Gi0/1       1-3

Port        Vlans in spanning tree forwarding state and not pruned
Gi0/1       1-3

SW1# show vlan id 2
VLAN Name                             Status    Ports
---- -------------------------------- --------- -------------------------------
2    Freds-vlan                       active    Fa0/13, Fa0/14, G0/1
VLAN Type  SAID       MTU   Parent RingNo BridgeNo Stp  BrdgMode Trans1 Trans2
---- ----- ---------- ----- ------ ------ -------- ---- -------- ------ ------
2    enet  100010     1500  -      -      -        -    -        0      0

Remote SPAN VLAN
----------------
Disabled

Primary Secondary Type              Ports
------- --------- ----------------- ------------------------------------------
```

```
! The three lists of VLANs in the next command list allowed VLANs (1-4094),
! Allowed and active VLANs (1-3), and allowed/active/not pruned/STP forwarding
! VLANs (1-3)
SW1# show interfaces trunk

Port        Mode         Encapsulation  Status        Native vlan
Gi0/1       desirable    802.1q         trunking      1

Port        Vlans allowed on trunk
Gi0/1       1-4094

Port        Vlans allowed and active in management domain
Gi0/1       1-3

Port        Vlans in spanning tree forwarding state and not pruned
Gi0/1       1-3

! Next, the switch is configured with new VLAN 4; VLAN 2 is shutdown;
! and VLAN 3 is removed from the allowed VLAN list on the trunk.
SW1# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
SW1(config)# vlan 4
SW1(config-vlan)# vlan 2
SW1(config-vlan)# shutdown
```

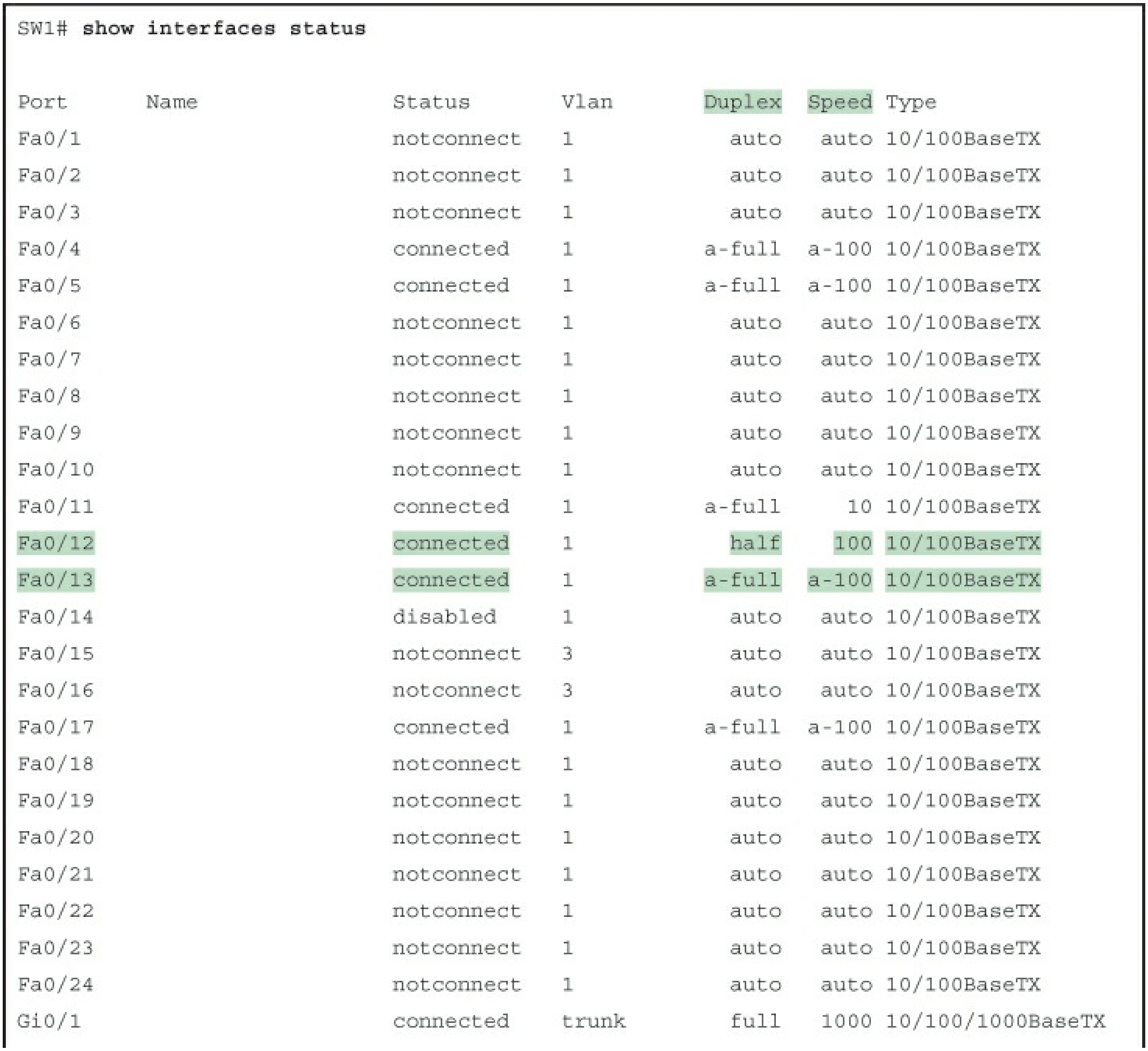
```
SW1(config-vlan)# interface gi0/1
SW1(config-if)# switchport trunk allowed vlan remove 3
SW1(config-if)# ^Z

! The three lists of VLANs in the next command list allowed VLANs (1-2, 4-4094),
! allowed and active VLANs (1,4), and allowed/active/not pruned/STP forwarding
! VLANs (1,4)
SW1# show interfaces trunk

Port        Mode         Encapsulation  Status        Native vlan
Gi0/1       desirable    802.1q         trunking      1

! VLAN 3 is omitted next, because it was removed from the allowed VLAN list.
Port        Vlans allowed on trunk
Gi0/1       1-2,4-4094

! VLAN 2 is omitted below because it is shutdown. VLANs 5-4094 are omitted below
! because SW1 does not have them configured.
Port        Vlans allowed and active in management domain
Gi0/1       1,4

Port        Vlans in spanning tree forwarding state and not pruned
Gi0/1       1,4
```

```
SW1# show interfaces gigabit0/1 switchport
Name: Gi0/1
Switchport: Enabled
Administrative Mode: trunk
Operational Mode: trunk
```

```
! The show cdp neighbors command lists SW2's local interface, and both R1's
! and SW1's interfaces  (in the "port" column), along with other details.
!
SW2# show cdp neighbors
Capability Codes: R - Router, T - Trans Bridge, B - Source Route Bridge
                  S - Switch, H - Host, I - IGMP, r - Repeater, P - Phone,
                  D - Remote, C - CVTA, M - Two-port Mac Relay

Device ID        Local Intrfce     Holdtme    Capability  Platform  Port ID
SW1              Gig 0/2           170             S I    WS-C2960- Gig 0/1
R1               Fas 0/13          136           R S I    CISCO2901 Gig 0/1

SW2# show cdp neighbors detail
-------------------------
Device ID: SW1
Entry address(es):
  IP address: 172.16.1.1
Platform: cisco WS-C2960-24TT-L,  Capabilities: Switch IGMP
Interface: GigabitEthernet0/2,  Port ID (outgoing port): GigabitEthernet0/1
Holdtime : 161 sec

Version :
Cisco IOS Software, C2960 Software (C2960-LANBASEK9-M), Version 15.0(1)SE3, RELEASE
SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
```

```
Copyright (c) 1986-2012 by Cisco Systems, Inc.
Compiled Wed 30-May-12 14:26 by prod_rel_team

advertisement version: 2
Protocol Hello:  OUI=0x00000C, Protocol ID=0x0112; payload len=27,
value=00000000FFFFFFFF010221FF000000000000018339D7B0E80FF0000
VTP Management Domain: ‘’
Native VLAN: 1
Duplex: full
Management address(es):
  IP address: 172.16.1.1

! This is a comment from the author: next lines are about R1.
-------------------------
Device ID: R1
Entry address(es):
  IP address: 10.1.1.9
Platform: Cisco CISCO2901/K9,  Capabilities: Router Switch IGMP
Interface: FastEthernet0/13,  Port ID (outgoing port): GigabitEthernet0/1
Holdtime : 127 sec

Version :
Cisco IOS Software, C2900 Software (C2900-UNIVERSALK9-M), Version 15.2(4)M1, RELEASE
SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2012 by Cisco Systems, Inc.
Compiled Thu 26-Jul-12 20:54 by prod_rel_team

advertisement version: 2
VTP Management Domain: ''
Duplex: full
Management address(es):
```

```
SW2# show cdp
Global CDP information:
    Sending CDP packets every 60 seconds
    Sending a holdtime value of 180 seconds
    Sending CDPv2 advertisements is enabled

SW2# show cdp interface FastEthernet0/13
FastEthernet0/13 is up, line protocol is up
  Encapsulation ARPA
  Sending CDP packets every 60 seconds
  Holdtime is 180 seconds

SW2# show cdp traffic
CDP counters :
    Total packets output: 304, Input: 305
    Hdr syntax: 0, Chksum error: 0, Encaps failed: 0
    No memory: 0, Invalid packet: 0,
    CDP version 1 advertisements output: 0, Input: 0
    CDP version 2 advertisements output: 304, Input: 305
```

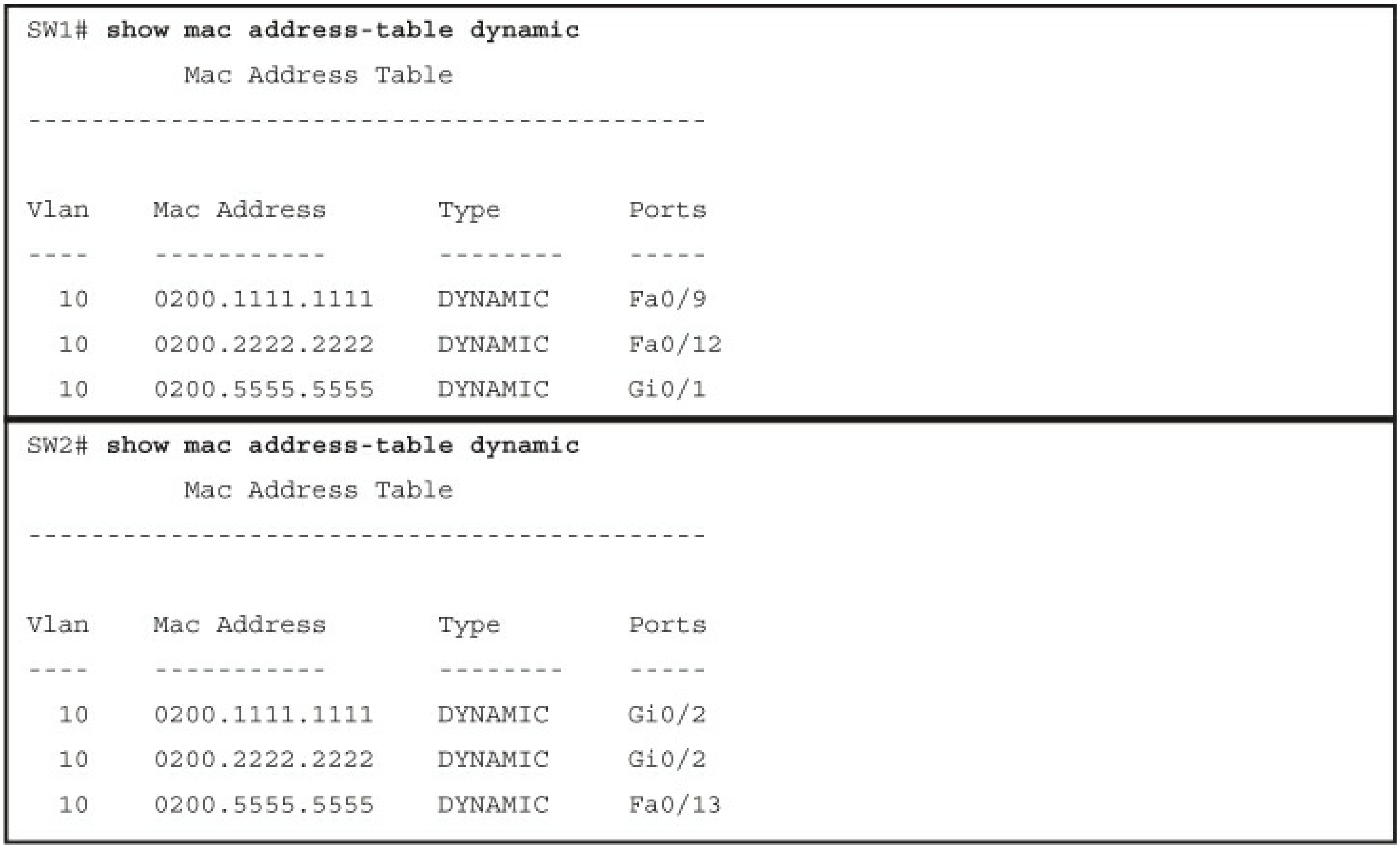


```
SW1# show interfaces status

Port      Name               Status       Vlan       Duplex  Speed Type
Fa0/1                        notconnect   1            auto   auto 10/100BaseTX
Fa0/2                        notconnect   1            auto   auto 10/100BaseTX
Fa0/3                        notconnect   1            auto   auto 10/100BaseTX
Fa0/4                        connected    1          a-full  a-100 10/100BaseTX
Fa0/5                        connected    1          a-full  a-100 10/100BaseTX
Fa0/6                        notconnect   1            auto   auto 10/100BaseTX
Fa0/7                        notconnect   1            auto   auto 10/100BaseTX
Fa0/8                        notconnect   1            auto   auto 10/100BaseTX
Fa0/9                        notconnect   1            auto   auto 10/100BaseTX
Fa0/10                       notconnect   1            auto   auto 10/100BaseTX
Fa0/11                       connected    1          a-full     10 10/100BaseTX
Fa0/12                       connected    1            half    100 10/100BaseTX
Fa0/13                       connected    1          a-full  a-100 10/100BaseTX
Fa0/14                       disabled     1            auto   auto 10/100BaseTX
Fa0/15                       notconnect   3            auto   auto 10/100BaseTX
Fa0/16                       notconnect   3            auto   auto 10/100BaseTX
Fa0/17                       connected    1          a-full  a-100 10/100BaseTX
Fa0/18                       notconnect   1            auto   auto 10/100BaseTX
Fa0/19                       notconnect   1            auto   auto 10/100BaseTX
Fa0/20                       notconnect   1            auto   auto 10/100BaseTX
Fa0/21                       notconnect   1            auto   auto 10/100BaseTX
Fa0/22                       notconnect   1            auto   auto 10/100BaseTX
Fa0/23                       notconnect   1            auto   auto 10/100BaseTX
Fa0/24                       notconnect   1            auto   auto 10/100BaseTX
Gi0/1                        connected    trunk        full   1000 10/100/1000BaseTX
```

```
Gi0/2                        notconnect   1            auto   auto 10/100/1000BaseTX

SW1# show interfaces fa0/13
FastEthernet0/13 is up, line protocol is up (connected)
  Hardware is Fast Ethernet, address is 0019.e86a.6f8d (bia 0019.e86a.6f8d)
  MTU 1500 bytes, BW 100000 Kbit, DLY 100 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation ARPA, loopback not set
  Keepalive set (10 sec)
  Full-duplex, 100Mbps, media type is 10/100BaseTX
  input flow-control is off, output flow-control is unsupported
  ARP type: ARPA, ARP Timeout 04:00:00
  Last input 00:00:05, output 00:00:00, output hang never
  Last clearing of "show interface" counters never
  Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
  Queueing strategy: fifo
  Output queue: 0/40 (size/max)
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
     85022 packets input, 10008976 bytes, 0 no buffer
     Received 284 broadcasts (0 multicast)
     0 runts, 0 giants, 0 throttles
     0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored
     0 watchdog, 281 multicast, 0 pause input
     0 input packets with dribble condition detected
     95226 packets output, 10849674 bytes, 0 underruns
     0 output errors, 0 collisions, 1 interface resets
     0 unknown protocol drops
     0 babbles, 0 late collision, 0 deferred
     0 lost carrier, 0 no carrier, 0 PAUSE output
     0 output buffer failures, 0 output buffers swapped out
```

```
SW1# show interfaces gi0/1 status

Port      Name               Status       Vlan       Duplex  Speed Type
Gi0/1                        connected    trunk      a-half  a-100 10/100/1000BaseTX
```

```
SW1# show interfaces fa0/13
! lines omitted for brevity
     Received 284 broadcasts (0 multicast)
     0 runts, 0 giants, 0 throttles
     0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored
     0 watchdog, 281 multicast, 0 pause input
     0 input packets with dribble condition detected
     95226 packets output, 10849674 bytes, 0 underruns
     0 output errors, 0 collisions, 1 interface resets
     0 unknown protocol drops
     0 babbles, 0 late collision, 0 deferred
     0 lost carrier, 0 no carrier, 0 PAUSE output
     0 output buffer failures, 0 output buffers swapped out
```



```
SW1# show mac address-table dynamic
          Mac Address Table
-------------------------------------------


Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
  10    0200.1111.1111    DYNAMIC     Fa0/9
  10    0200.2222.2222    DYNAMIC     Fa0/12
  10    0200.5555.5555    DYNAMIC     Gi0/1
```

```
SW2# show mac address-table dynamic
          Mac Address Table
-------------------------------------------


Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
  10    0200.1111.1111    DYNAMIC     Gi0/2
  10    0200.2222.2222    DYNAMIC     Gi0/2
  10    0200.5555.5555    DYNAMIC     Fa0/13
```

```
SW2# show vlan brief

VLAN Name                             Status    Ports
---- -------------------------------- --------- -------------------------------
1    default                          active    Fa0/1, Fa0/2, Fa0/3, Fa0/4
                                                Fa0/5, Fa0/6, Fa0/7, Fa0/8
                                                Fa0/9, Fa0/10, Fa0/11, Fa0/12
                                                Fa0/14, Fa0/15, Fa0/16, Fa0/17
                                                Fa0/18, Fa0/19, Fa0/20, Fa0/21
                                                Fa0/22, Fa0/23, Fa0/24, Gi0/1
10   VLAN0010                         act/lshut Fa0/13
20   VLAN0020                         active
30   VLAN0030                         act/lshut
40   VLAN0040                         active
SW2#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
SW2(config)# no shutdown vlan 10
SW2(config)# shutdown vlan 20
SW2(config)# vlan 30
SW2(config-vlan)# no shutdown
SW2(config-vlan)# vlan 40
SW2(config-vlan)# shutdown
SW2(config-vlan)#
```

```
SW2# show interfaces trunk

Port        Mode         Encapsulation  Status        Native vlan
Gi0/2       desirable    802.1q         trunking      1

Port        Vlans allowed on trunk
Gi0/2       1-4094

Port        Vlans allowed and active in management domain
Gi0/2       1-9

Port        Vlans in spanning tree forwarding state and not pruned
Gi0/2       1-9
```

```
SW2# show interfaces gigabit0/2 switchport
Name: Gi0/2
Switchport: Enabled
Administrative Mode: dynamic auto
Operational Mode: static access
Administrative Trunking Encapsulation: dot1q
Operational Trunking Encapsulation: native
! lines omitted for brevity
```

```
R1# show ip interface brief
Interface                  IP-Address      OK? Method Status                Protocol
Embedded-Service-Engine0/0 unassigned      YES NVRAM  administratively down down
GigabitEthernet0/0         172.16.1.1      YES NVRAM  down                  down
GigabitEthernet0/1         unassigned      YES manual administratively down down
Serial0/0/0                172.16.4.1      YES NVRAM  up                    up
Serial0/0/1                172.16.5.1      YES NVRAM  up                    up
Serial0/1/0                unassigned      YES NVRAM  up                    up
Serial0/1/1                unassigned      YES NVRAM  administratively down down

R1# show interfaces serial 0/0/0
Serial0/0/0 is up, line protocol is up
  Hardware is WIC MBRD Serial
  Description: Link in lab to R2's S0/0/1
  Internet address is 172.16.4.1/24
  MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation HDLC, loopback not set
  Keepalive set (10 sec)
  Last input 00:00:03, output 00:00:06, output hang never
  Last clearing of "show interface" counters never
  Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
  Queueing strategy: fifo
  Output queue: 0/40 (size/max)
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
     42 packets input, 3584 bytes, 0 no buffer
     Received 42 broadcasts (0 IP multicasts)
     0 runts, 0 giants, 0 throttles
     0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored, 0 abort
     41 packets output, 3481 bytes, 0 underruns
     0 output errors, 0 collisions, 4 interface resets
     3 unknown protocol drops
     0 output buffer failures, 0 output buffers swapped out
     0 carrier transitions
     DCD=up  DSR=up  DTR=up  RTS=up  CTS=up
```

```
R1# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R1config)# interface G0/0
R1(config-if)# ip address 172.16.1.1 255.255.255.0
R1(config-if)# no shutdown
R1(config-if)# interface S0/0/0
R1(config-if)# ip address 172.16.4.1 255.255.255.0
R1(config-if)# no shutdown
R1(config-if)# interface S0/0/1
R1(config-if)# ip address 172.16.5.1 255.255.255.0
R1(config-if)# no shutdown
R1(config-if)# ^Z
R1#
```

```
R1# show protocols
Global values:
  Internet Protocol routing is enabled
Embedded-Service-Engine0/0 is administratively down, line protocol is down
GigabitEthernet0/0 is up, line protocol is up
  Internet address is 172.16.1.1/24
GigabitEthernet0/1 is administratively down, line protocol is down
Serial0/0/0 is up, line protocol is up
  Internet address is 172.16.4.1/24
Serial0/0/1 is up, line protocol is up
  Internet address is 172.16.5.1/24
Serial0/1/0 is administratively down, line protocol is down
Serial0/1/1 is administratively down, line protocol is down
```

```
R1# show running-config
! lines omitted for brevity
interface Serial0/0/0
 ip address 172.16.4.1 255.255.255.0
 clock rate 2000000
!
interface Serial0/0/1
 ip address 172.16.5.1 255.255.255.0
 clock rate 128000

! lines omitted for brevity

R1# show controllers serial 0/0/1
Interface Serial0
Hardware is PowerQUICC MPC860
DCE V.35, clock rate 128000
idb at 0x8169BB20, driver data structure at 0x816A35E4
! Lines omitted for brevity
```

```
R1# show version
Cisco IOS Software, C2900 Software (C2900-UNIVERSALK9-M), Version 15.2(4)M1, RELEASE
SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2012 by Cisco Systems, Inc.
Compiled Thu 26-Jul-12 20:54 by prod_rel_team

ROM: System Bootstrap, Version 15.0(1r)M15, RELEASE SOFTWARE (fc1)

R1 uptime is 3 days, 4 hours, 19 minutes
System returned to ROM by reload at 14:00:46 UTC Sat Oct 13 2012
System image file is "flash:c2900-universalk9-mz.SPA.152-4.M1.bin"
Last reload type: Normal Reload
Last reload reason: Reload Command


! Legal notices omitted for brevity

If you require further assistance please contact us by sending email to
export@cisco.com.

Cisco CISCO2901/K9 (revision 1.0) with 483328K/40960K bytes of memory.
Processor board ID FTX1628838P
2 Gigabit Ethernet interfaces
4 Serial(sync/async) interfaces
1 terminal line
DRAM configuration is 64 bits wide with parity enabled.
255K bytes of non-volatile configuration memory.
3425968K bytes of USB Flash usbflash1 (Read/Write)
250880K bytes of ATA System CompactFlash 0 (Read/Write)


License Info:

! License information omitted for brevity

Configuration register is 0x2102
```

```
! Excerpt from show running-config follows...
!
interface GigabitEthernet0/0
 ip address 172.16.1.1 255.255.255.0
!
interface Serial0/0/0
 ip address 172.16.4.1 255.255.255.0
!
interface Serial0/0/1
 ip address 172.16.5.1 255.255.255.0

R1# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      172.16.0.0/16 is variably subnetted, 6 subnets, 2 masks
C        172.16.1.0/24 is directly connected, GigabitEthernet0/0
L        172.16.1.1/32 is directly connected, GigabitEthernet0/0
C        172.16.4.0/24 is directly connected, Serial0/0/0
L        172.16.4.1/32 is directly connected, Serial0/0/0
C        172.16.5.0/24 is directly connected, Serial0/0/1
L        172.16.5.1/32 is directly connected, Serial0/0/1
```

```
B1# show running-config
! Only pertinent lines shown
interface gigabitethernet 0/0
! No IP address up here! No encapsulation up here!
!
interface gigabitethernet 0/0.10
 encapsulation dot1q 10
 ip address 10.1.10.1 255.255.255.0
!
interface gigabitethernet 0/0.20
 encapsulation dot1q 20
 ip address 10.1.20.1 255.255.255.0
!
B1# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
! Lines omitted for brevity

      10.0.0.0/8 is variably subnetted, 4 subnets, 2 masks
C        10.1.10.0/24 is directly connected, GigabitEthernet0/0.10
L        10.1.10.1/32 is directly connected, GigabitEthernet0/0.10
C        10.1.20.0/24 is directly connected, GigabitEthernet0/0.20
L        10.1.20.1/32 is directly connected, GigabitEthernet0/0.20
```

```
! First option: put the native VLAN IP address on the
! physical interface
interface gigabitethernet 0/0
 ip address 10.1.10.1 255.255.255.0
!
interface gigabitethernet 0/0.20
 encapsulation dot1q 20
 ip address 10.1.20.1 255.255.255.0
```

```
! Second option: like normal, but add the native keyword
interface gigabitethernet 0/0.10
 encapsulation dot1q 10 native
 ip address 10.1.10.1 255.255.255.0
!
interface gigabitethernet 0/0.20
 encapsulation dot1q 20
 ip address 10.1.20.1 255.255.255.0
```

```
R1# show vlans

Virtual LAN ID:  1 (IEEE 802.1Q Encapsulation)

   vLAN Trunk Interface:   GigabitEthernet0/0

   Protocols Configured:   Address:              Received:        Transmitted:
        Other                                            0                 83

   69 packets, 20914 bytes input
   147 packets, 11841 bytes output

Virtual LAN ID:  10 (IEEE 802.1Q Encapsulation)

   vLAN Trunk Interface:   GigabitEthernet0/0.10

 This is configured as native Vlan for the following interface(s) :
GigabitEthernet0/0

   Protocols Configured:   Address:              Received:        Transmitted:
           IP              10.1.10.1                     2                  3
        Other                                            0                  1

   3 packets, 722 bytes input
   4 packets, 264 bytes output

Virtual LAN ID:  20 (IEEE 802.1Q Encapsulation)

   vLAN Trunk Interface:   GigabitEthernet0/0.20

   Protocols Configured:   Address:              Received:        Transmitted:
           IP              10.1.20.1                     0                134
        Other                                            0                  1

   0 packets, 0 bytes input
   135 packets, 10498 bytes output
```

```
ip routing
!
interface vlan 10
 ip address 10.1.10.1 255.255.255.0
!
interface vlan 20
 ip address 10.1.20.1 255.255.255.0
!
interface vlan 30
 ip address 10.1.30.1 255.255.255.0
```

```
SW1# show ip route
! legend omitted for brevity

      10.0.0.0/8 is variably subnetted, 6 subnets, 2 masks
C         10.1.10.0/24 is directly connected, Vlan10
L         10.1.10.1/32 is directly connected, Vlan10
C         10.1.20.0/24 is directly connected, Vlan20
L         10.1.20.1/32 is directly connected, Vlan20
C         10.1.30.0/24 is directly connected, Vlan30
L         10.1.30.1/32 is directly connected, Vlan30
```

```
! Excerpt from show running-config follows...
interface gigabitethernet 0/0
 ip address 172.16.9.1  255.255.255.0 secondary
 ip address 172.16.1.1  255.255.255.0

R1# show ip route connected
! lines omitted for brevity
      172.16.0.0/16 is variably subnetted, 8 subnets, 2 masks
C        172.16.1.0/24 is directly connected, GigabitEthernet0/0
L        172.16.1.1/32 is directly connected, GigabitEthernet0/0
C        172.16.9.0/24 is directly connected, GigabitEthernet0/0
L        172.16.9.1/32 is directly connected, GigabitEthernet0/0
```

```
R1# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R1(config)# interface g0/1
R1(config-if)# ip address 10.0.0.1 255.255.255.0
R1(config-if)# no ip address
R1(config-if)# exit
R1(config)# no ip subnet-zero
R1(config)# interface g0/1
R1(config-if)# ip address 10.0.0.1 255.255.255.0
Bad mask /24 for address 10.0.0.1
```

```
ip route 172.16.2.0 255.255.255.0 172.16.4.2
ip route 172.16.3.0 255.255.255.0 S0/0/1
```

```
R1# show ip route static
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
! lines omitted for brevity
Gateway of last resort is not set

      172.16.0.0/16 is variably subnetted, 10 subnets, 2 masks
S        172.16.2.0/24 [1/0] via 172.16.4.2
S        172.16.3.0/24 is directly connected, Serial0/0/1
```

```
R2# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R2(config)# ip route 0.0.0.0 0.0.0.0 s0/0/1
R2(config)# ^Z
R2# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is 0.0.0.0 to network 0.0.0.0


S*    0.0.0.0/0 is directly connected, Serial0/0/1
      172.16.0.0/16 is variably subnetted, 4 subnets, 2 masks
C        172.16.2.0/24 is directly connected, GigabitEthernet0/0
L        172.16.2.2/32 is directly connected, GigabitEthernet0/0
C        172.16.4.0/24 is directly connected, Serial0/0/1
L        172.16.4.2/32 is directly connected, Serial0/0/1
```

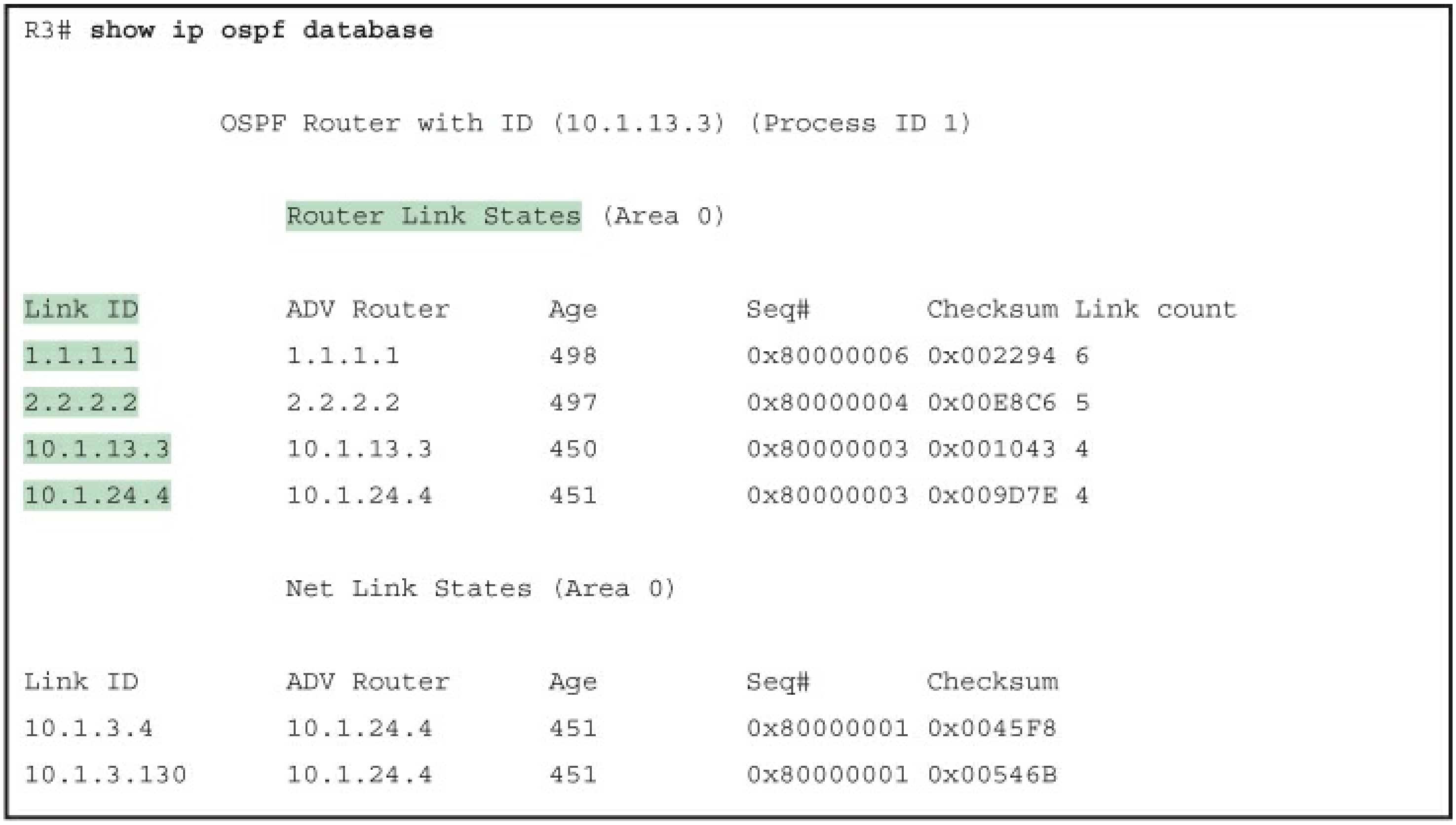
```
interface gigabitethernet 0/0.341
 encapsulation dot1q 341
 ip address 10.1.3.1 255.255.255.128
!
interface gigabitethernet 0/0.342
 encapsulation dot1q 342
 ip address 10.1.3.129 255.255.255.128
!
interface serial 0/0/0
 ip address 10.1.13.3 255.255.255.128
```

```
router ospf 1
 network 10.0.0.0 0.255.255.255 area 0
```

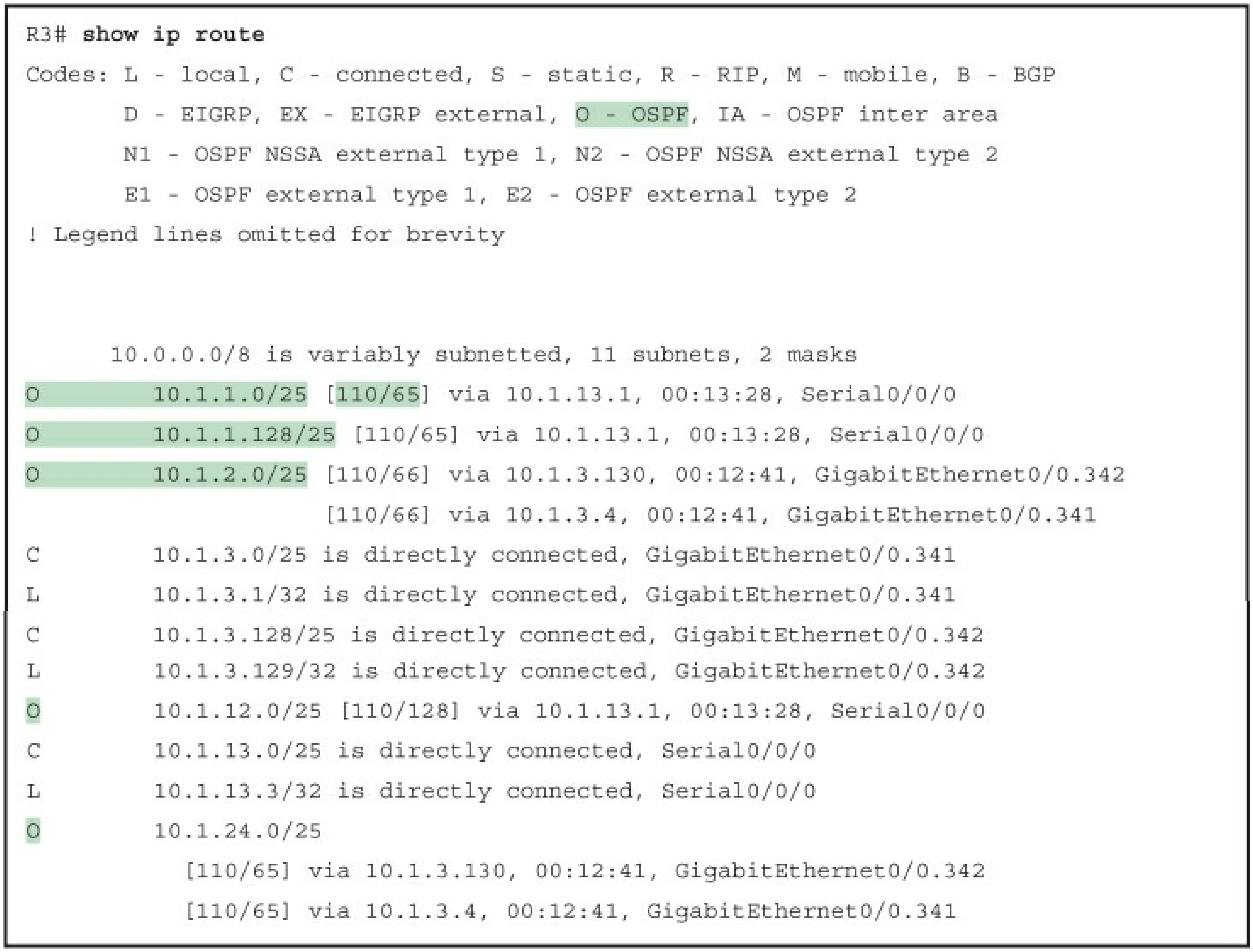
```
! R1 configuration next - one network command enables OSPF
! on all three interfaces
router ospf 1
 network 10.1.0.0 0.0.255.255 area 0
```

```
! R2 configuration next - One network command per interface
router ospf 1
 network 10.1.12.2 0.0.0.0 area 0
 network 10.1.24.2 0.0.0.0 area 0
 network 10.1.2.2 0.0.0.0 area 0
```

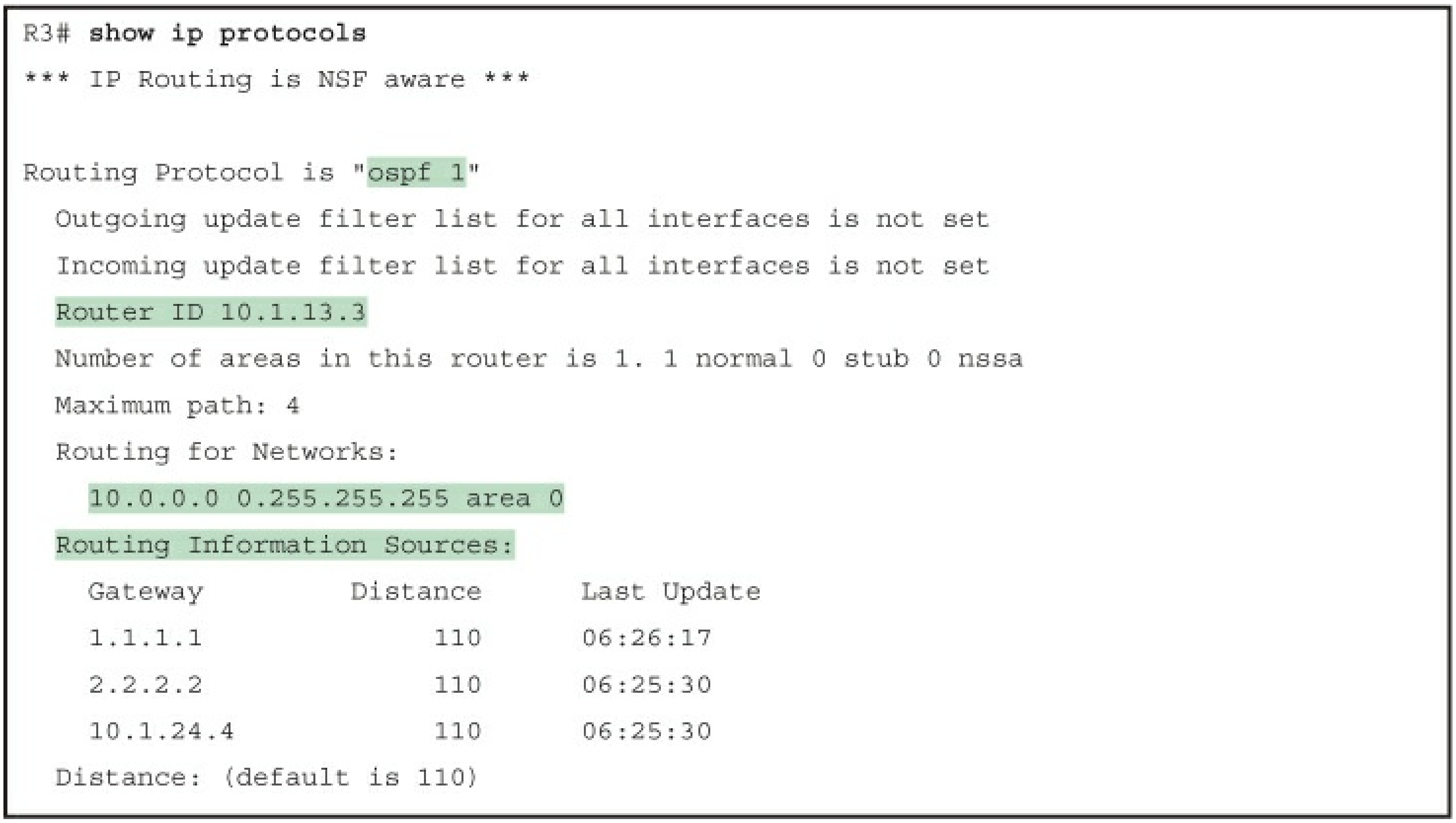
```
R3# show ip ospf neighbor

Neighbor ID     Pri   State        Dead Time   Address         Interface
1.1.1.1           0   FULL/  -     00:00:33    10.1.13.1       Serial0/0/0
10.1.24.4         1   FULL/DR      00:00:35    10.1.3.130      GigabitEthernet0/0.342
10.1.24.4         1   FULL/DR      00:00:36    10.1.3.4        GigabitEthernet0/0.341
```



```
R3# show ip ospf database

            OSPF Router with ID (10.1.13.3) (Process ID 1)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link count
1.1.1.1         1.1.1.1         498         0x80000006 0x002294 6
2.2.2.2         2.2.2.2         497         0x80000004 0x00E8C6 5
10.1.13.3       10.1.13.3       450         0x80000003 0x001043 4
10.1.24.4       10.1.24.4       451         0x80000003 0x009D7E 4

                Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.3.4        10.1.24.4       451         0x80000001 0x0045F8
10.1.3.130      10.1.24.4       451         0x80000001 0x00546B
```



```
R3# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
! Legend lines omitted for brevity


      10.0.0.0/8 is variably subnetted, 11 subnets, 2 masks
O        10.1.1.0/25 [110/65] via 10.1.13.1, 00:13:28, Serial0/0/0
O        10.1.1.128/25 [110/65] via 10.1.13.1, 00:13:28, Serial0/0/0
O        10.1.2.0/25 [110/66] via 10.1.3.130, 00:12:41, GigabitEthernet0/0.342
                     [110/66] via 10.1.3.4, 00:12:41, GigabitEthernet0/0.341
C        10.1.3.0/25 is directly connected, GigabitEthernet0/0.341
L        10.1.3.1/32 is directly connected, GigabitEthernet0/0.341
C        10.1.3.128/25 is directly connected, GigabitEthernet0/0.342
L        10.1.3.129/32 is directly connected, GigabitEthernet0/0.342
O        10.1.12.0/25 [110/128] via 10.1.13.1, 00:13:28, Serial0/0/0
C        10.1.13.0/25 is directly connected, Serial0/0/0
L        10.1.13.3/32 is directly connected, Serial0/0/0
O        10.1.24.0/25
           [110/65] via 10.1.3.130, 00:12:41, GigabitEthernet0/0.342
           [110/65] via 10.1.3.4, 00:12:41, GigabitEthernet0/0.341
```



```
R3# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "ospf 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 10.1.13.3
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    10.0.0.0 0.255.255.255 area 0
  Routing Information Sources:
    Gateway         Distance      Last Update
    1.1.1.1              110      06:26:17
    2.2.2.2              110      06:25:30
    10.1.24.4            110      06:25:30
  Distance: (default is 110)
```

```
! R1 Configuration first
router ospf 1
 router-id 1.1.1.1
 network 10.1.0.0 0.0.255.255 area 0
 network 10.0.0.0 0.255.255.255 area 0
```

```
! R2 Configuration next
!
interface Loopback2
 ip address 2.2.2.2 255.255.255.255
```

```
R1# show ip ospf
 Routing Process “ospf 1” with ID 1.1.1.1
! lines omitted for brevity
! First, make each subinterface passive directly
router ospf 1
 passive-interface gigabitethernet0/0.11
 passive-interface gigabitethernet0/0.12

! Or, change the default to passive, and make the other interfaces
! not be passive

router ospf 1
 passive-interface default
 no passive-interface serial0/0/0
 no passive-interface serial0/0/1
```

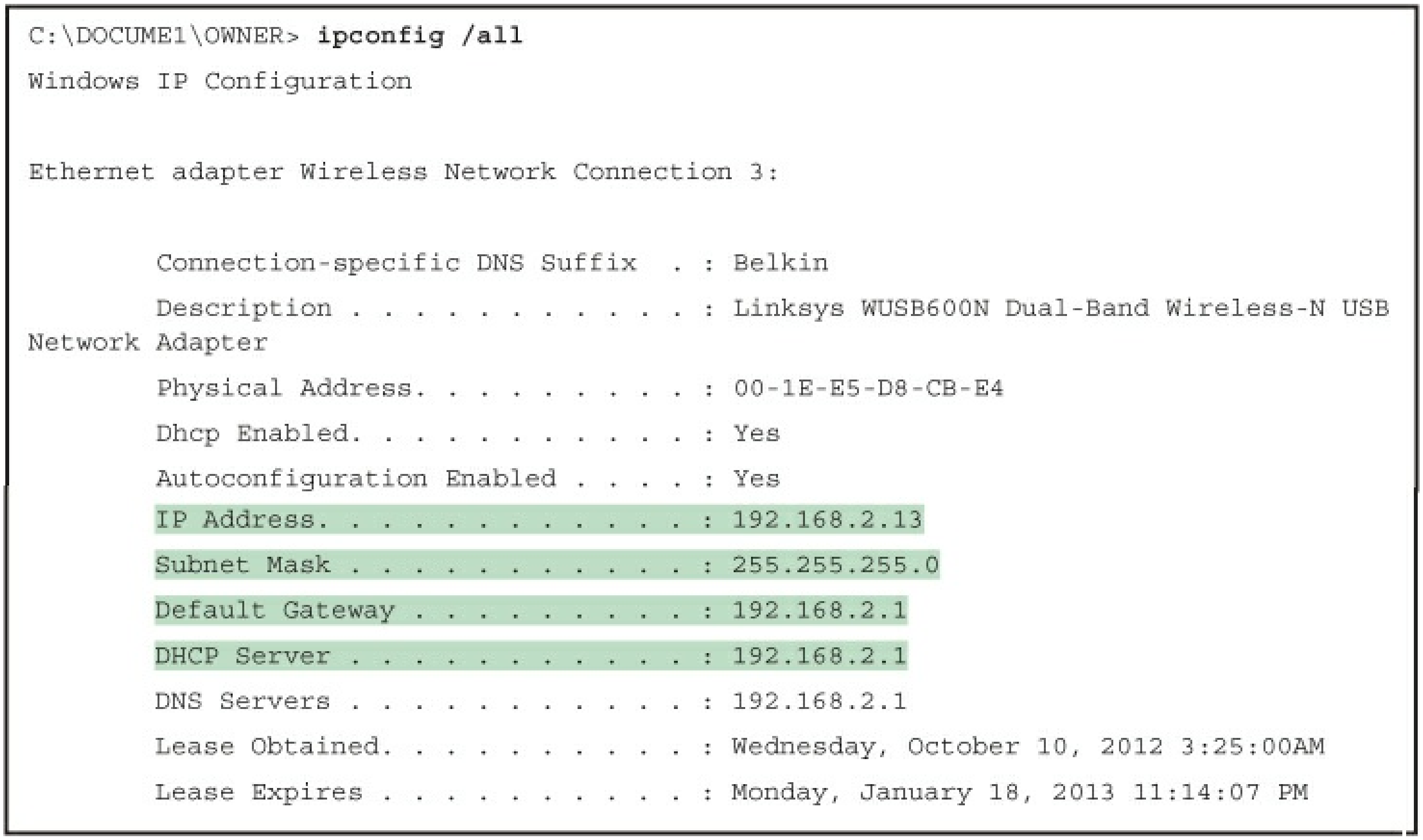
```
R1# show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Gi0/0.12     1     0               10.1.1.129/25      1     DR    0/0
Gi0/0.11     1     0               10.1.1.1/25        1     DR    0/0
Se0/0/0      1     0               10.1.12.1/25       64    P2P   0/0
Se0/0/1      1     0               10.1.13.1/25       64    P2P   0/0

R1# show ip ospf interface g0/0.11
GigabitEthernet0/0.1 is up, line protocol is up
  Internet Address 10.1.1.1/25, Area 0, Attached via Network Statement
  Process ID 1, Router ID 10.1.1.129, Network Type BROADCAST, Cost: 1
  Topology-MTID    Cost    Disabled    Shutdown      Topology Name
        0           1         no          no            Base
  Transmit Delay is 1 sec, State DR, Priority 1
  Designated Router (ID) 10.1.1.129, Interface address 10.1.1.1
  No backup designated router on this network
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    oob-resync timeout 40
    No Hellos (Passive interface)
! Lines omitted for brevity
```

```
R1# show sessions
Conn Host                Address          Byte  Idle Conn Name
   1 Fred                 10.1.1.1         0     0    Fred
*  2 Barney              10.1.2.1         0     0    Barney
```

```
ip dhcp excluded-address 172.16.1.1 172.16.1.50
ip dhcp excluded-address 172.16.2.1 172.16.2.100
!
ip dhcp pool subnet-left
 network 172.16.1.0 255.255.255.0
 dns-server 172.16.1.12
 default-router 172.16.1.1
 lease 0 23 59
 domain-name example.com
!
ip dhcp pool subnet-right
 network 172.16.2.0 /24
 dns-server 172.16.1.12
 default-router 172.16.2.1
 lease 1 2 3
```

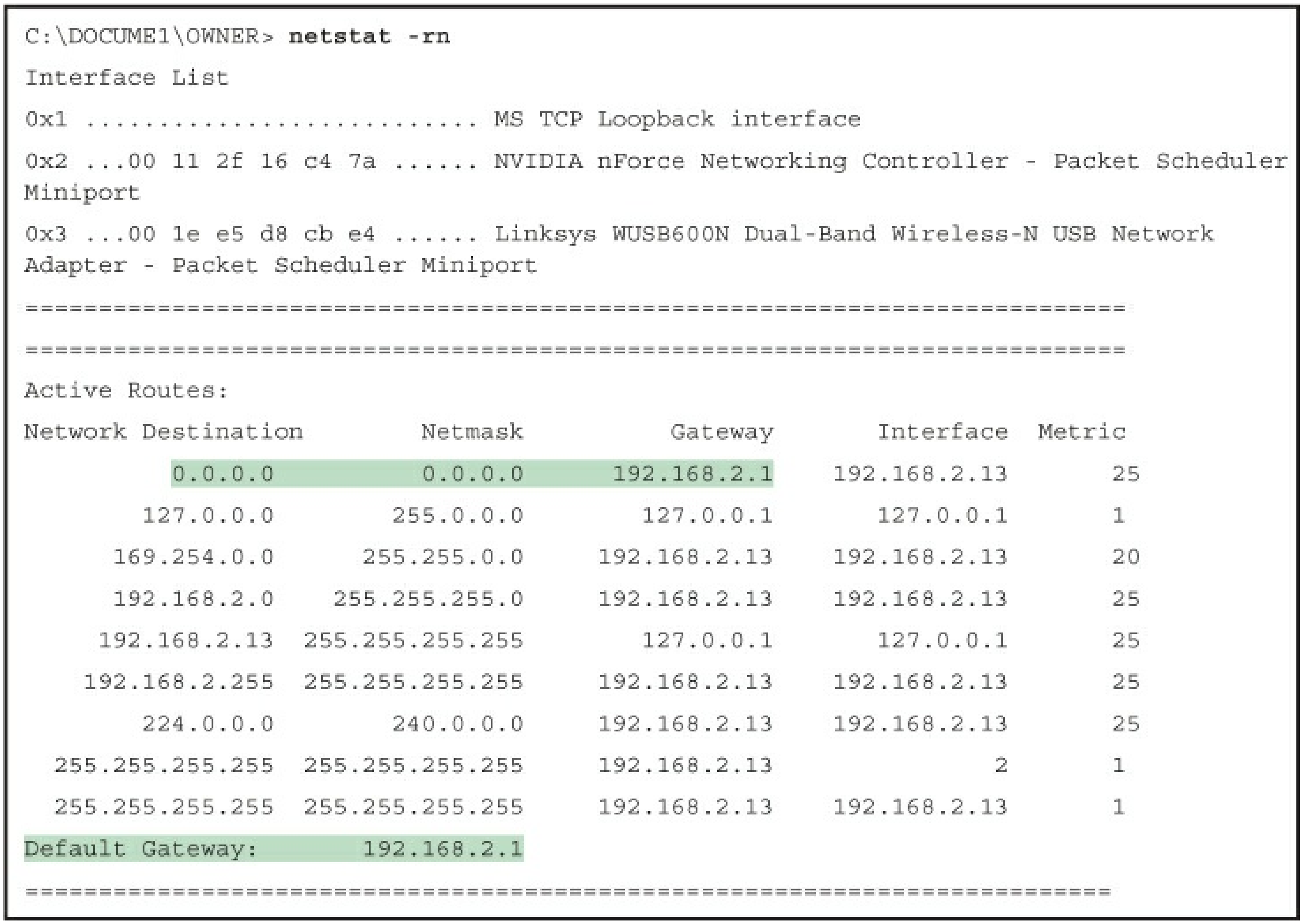
```
R2# show ip dhcp binding
Bindings from all pools not associated with VRF:
IP address          Client-ID/              Lease expiration        Type
                    Hardware address/
                    User name
172.16.1.51         0063.6973.636f.2d30.    Oct 12 2012 02:56 AM    Automatic
                    3230.302e.3131.3131.
                    2e31.3131.312d.4661.
                    302f.30
172.16.2.101        0063.6973.636f.2d30.    Oct 12 2012 04:59 AM    Automatic
                    3230.302e.3232.3232.
                    2e32.3232.322d.4769.
                    302f.30
R2# show ip dhcp pool subnet-right
Pool subnet-right :
 Utilization mark (high/low)    : 100 / 0
 Subnet size (first/next)       : 0 / 0
 Total addresses                : 254
 Leased addresses               : 1
 Pending event                  : none
 1 subnet is currently in the pool :
 Current index        IP address range                    Leased addresses
 172.16.2.102         172.16.2.1       - 172.16.2.254      1
```

```
*Oct 16 19:28:59.220: %DHCPD-4-DECLINE_CONFLICT: DHCP address conflict:  client
0063.6973.636f.2d30.3230.302e.3034.3034.2e30.3430.342d.4769.302f.30 declined
172.16.2.102.
R2# show ip dhcp conflict
IP address        Detection method   Detection time          VRF
172.16.2.102      Gratuitous ARP     Oct 16 2012 07:28 PM
```



```
C:\DOCUME1\OWNER> ipconfig /all
Windows IP Configuration


Ethernet adapter Wireless Network Connection 3:


        Connection-specific DNS Suffix  . : Belkin
        Description . . . . . . . . . . . : Linksys WUSB600N Dual-Band Wireless-N USB
Network Adapter
        Physical Address. . . . . . . . . : 00-1E-E5-D8-CB-E4
        Dhcp Enabled. . . . . . . . . . . : Yes
        Autoconfiguration Enabled . . . . : Yes
        IP Address. . . . . . . . . . . . : 192.168.2.13
        Subnet Mask . . . . . . . . . . . : 255.255.255.0
        Default Gateway . . . . . . . . . : 192.168.2.1
        DHCP Server . . . . . . . . . . . : 192.168.2.1
        DNS Servers . . . . . . . . . . . : 192.168.2.1
        Lease Obtained. . . . . . . . . . : Wednesday, October 10, 2012 3:25:00AM
        Lease Expires . . . . . . . . . . : Monday, January 18, 2013 11:14:07 PM
```

```
Wendell-Odoms-iMac: wendellodom$ nslookup www.certskills.com
Server:         209.18.47.61
Address:        209.18.47.61#53

Non-authoritative answer:
www.certskills.com    canonical name = certskills.com.
Name:    certskills.com
Address: 173.227.251.150
```

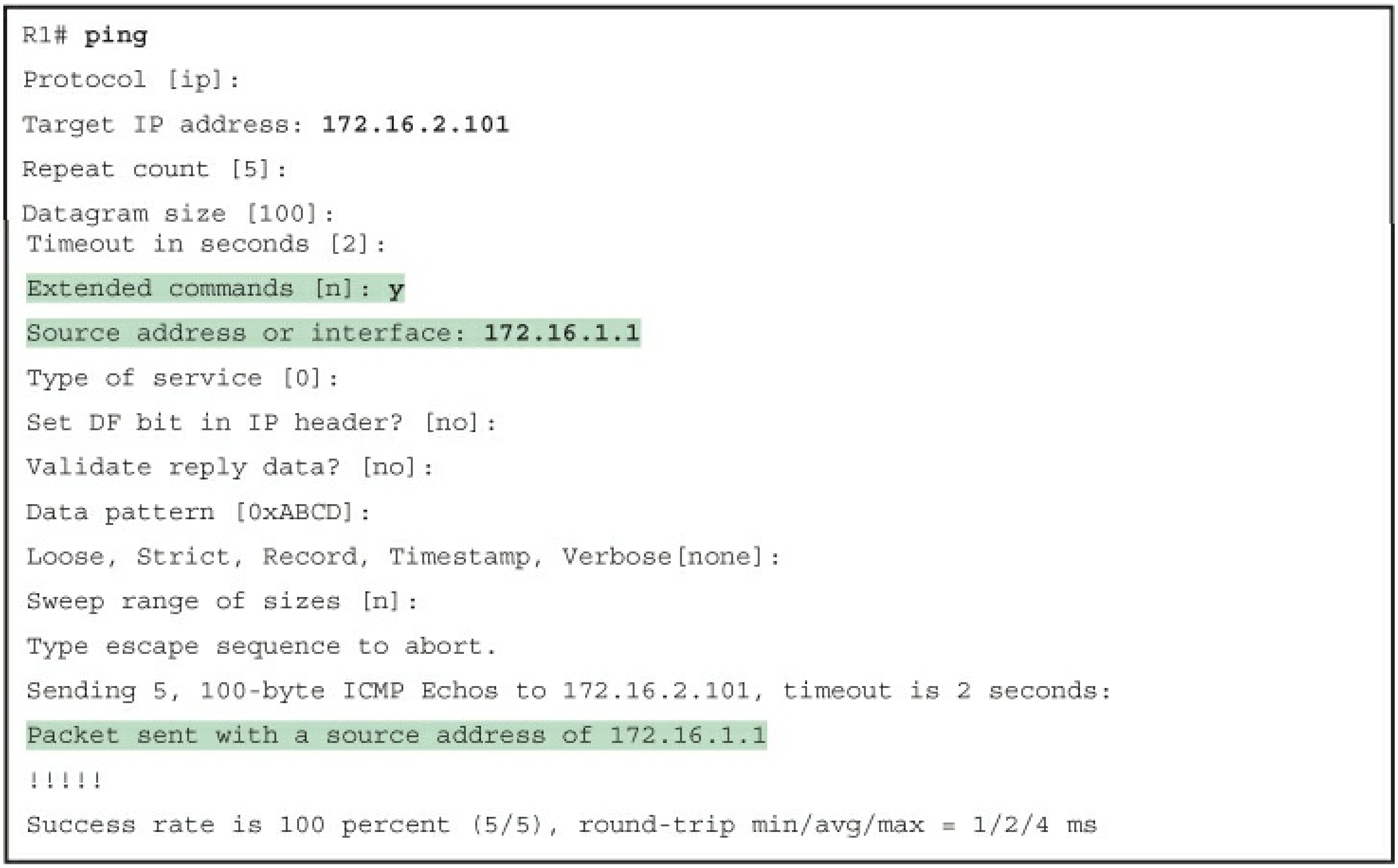


```
C:\DOCUME1\OWNER> netstat -rn
Interface List
0x1 ........................... MS TCP Loopback interface
0x2 ...00 11 2f 16 c4 7a ...... NVIDIA nForce Networking Controller - Packet Scheduler
Miniport
0x3 ...00 1e e5 d8 cb e4 ...... Linksys WUSB600N Dual-Band Wireless-N USB Network
Adapter - Packet Scheduler Miniport
===========================================================================
===========================================================================
Active Routes:
Network Destination        Netmask          Gateway       Interface  Metric
          0.0.0.0          0.0.0.0      192.168.2.1    192.168.2.13       25
        127.0.0.0        255.0.0.0        127.0.0.1       127.0.0.1        1
      169.254.0.0      255.255.0.0     192.168.2.13    192.168.2.13       20
      192.168.2.0    255.255.255.0     192.168.2.13    192.168.2.13       25
     192.168.2.13  255.255.255.255        127.0.0.1       127.0.0.1       25
    192.168.2.255  255.255.255.255     192.168.2.13    192.168.2.13       25
        224.0.0.0        240.0.0.0     192.168.2.13    192.168.2.13       25
  255.255.255.255  255.255.255.255     192.168.2.13               2        1
  255.255.255.255  255.255.255.255     192.168.2.13    192.168.2.13        1
Default Gateway:       192.168.2.1
==========================================================================
C:\Users\wodom> arp -a


Interface: 172.16.1.9 --- 0xa
  Internet Address      Physical Address      Type
  172.16.1.1            02-00-01-01-01-01     dynamic
  172.16.1.8            00-50-56-e5-d4-72     dynamic
```

```
R1# show arp
Protocol  Address          Age (min)  Hardware Addr   Type   Interface
Internet  172.16.1.1               -  0200.0101.0101  ARPA   GigabitEthernet0/0
Internet  172.16.1.9               2  0200.1111.1111  ARPA   GigabitEthernet0/0
```

```
Wendell-Odoms-iMac: wendellodom$ ping 172.16.2.101
PING 172.16.2.101 (172.16.2.101): 56 data bytes
64 bytes from 172.16.2.101: icmp_seq=0 ttl=64 time=1.112 ms
64 bytes from 172.16.2.101: icmp_seq=1 ttl=64 time=0.673 ms
64 bytes from 172.16.2.101: icmp_seq=2 ttl=64 time=0.631 ms
64 bytes from 172.16.2.101: icmp_seq=3 ttl=64 time=0.674 ms
64 bytes from 172.16.2.101: icmp_seq=4 ttl=64 time=0.642 ms
64 bytes from 172.16.2.101: icmp_seq=5 ttl=64 time=0.656 ms
^C
--- 172.16.2.101 ping statistics ---
6 packets transmitted, 6 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 0.631/0.731/1.112/0.171 ms
```

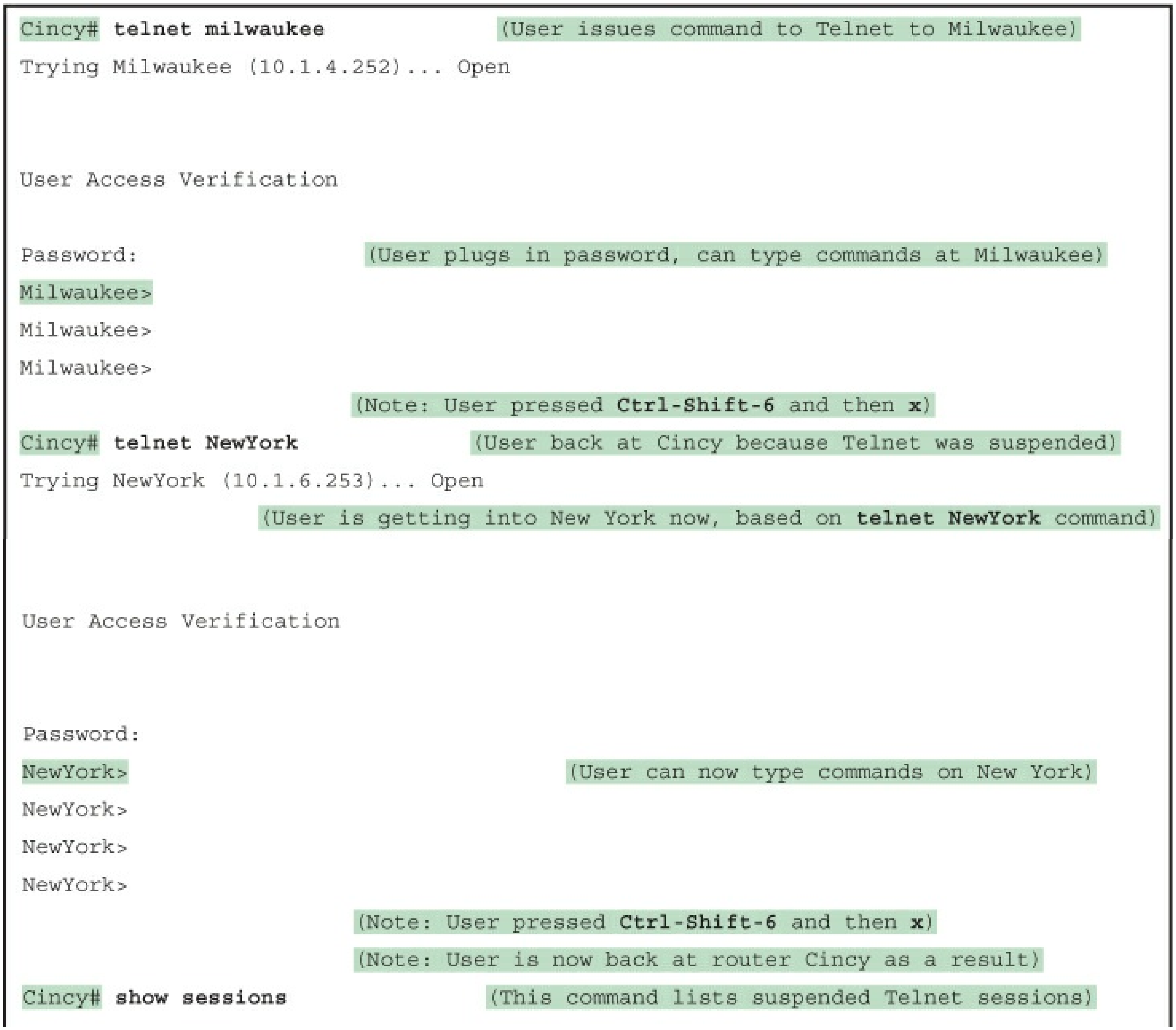
```
R1# ping 172.16.2.101
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.101, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 1/2/4 ms
R1# ping 172.16.2.101
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.101, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/2/4 ms
```



```
R1# ping
Protocol [ip]:
Target IP address: 172.16.2.101
Repeat count [5]:
Datagram size [100]:
Timeout in seconds [2]:
Extended commands [n]: y
Source address or interface: 172.16.1.1
Type of service [0]:
Set DF bit in IP header? [no]:
Validate reply data? [no]:
Data pattern [0xABCD]:
Loose, Strict, Record, Timestamp, Verbose[none]:
Sweep range of sizes [n]:
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.101, timeout is 2 seconds:
Packet sent with a source address of 172.16.1.1
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/2/4 ms
```

```
Wendell-Odoms-iMac: wendellodom$ traceroute 172.16.2.101
traceroute to 172.16.2.101, 64 hops max, 52 byte packets
 1  172.16.1.1 (172.16.1.1)  0.870 ms  0.520 ms  0.496 ms
 2  172.16.4.2 (172.16.4.2) 8.263 ms  7.518 ms  9.319 ms
 3  172.16.2.101 (172.16.2.101) 16.770 ms  9.819 ms  9.830 ms
```

```
R1# traceroute 172.16.2.101
Type escape sequence to abort.
Tracing the route to 172.16.2.101
VRF info: (vrf in name/id, vrf out name/id)
  1 172.16.4.2 0 msec 0 msec 0 msec
  2 172.16.2.101 0 msec 0 msec *

R1# traceroute
Protocol [ip]:
Target IP address: 172.16.2.101
Source address: 172.16.1.1
Numeric display [n]:
Timeout in seconds [3]:
Probe count [3]:
Minimum Time to Live [1]:
Maximum Time to Live [30]:
Port Number [33434]:
Loose, Strict, Record, Timestamp, Verbose[none]:
Type escape sequence to abort.
Tracing the route to 172.16.2.101
VRF info: (vrf in name/id, vrf out name/id)
  1 172.16.4.2 0 msec 0 msec 0 msec
  2 172.16.2.101 0 msec 0 msec *
```



```
Cincy# telnet milwaukee              (User issues command to Telnet to Milwaukee)
Trying Milwaukee (10.1.4.252)... Open



User Access Verification


Password:                       (User plugs in password, can type commands at Milwaukee)
Milwaukee>
Milwaukee>
Milwaukee>
                               (Note: User pressed Ctrl-Shift-6 and then x)
Cincy# telnet NewYork              (User back at Cincy because Telnet was suspended)
Trying NewYork (10.1.6.253)... Open
                        (User is getting into New York now, based on telnet NewYork command)



User Access Verification



Password:
NewYork>                                      (User can now type commands on New York)
NewYork>
NewYork>
NewYork>
                               (Note: User pressed Ctrl-Shift-6 and then x)
                               (Note: User is now back at router Cincy as a result)
Cincy# show sessions                (This command lists suspended Telnet sessions)
```

```
Conn Host                Address             Byte  Idle Conn Name
   1 Milwaukee           10.1.4.252             0     0 Milwaukee
*  2 NewYork             10.1.6.253             0     0 NewYork

Cincy# where                          (where does the same thing as show sessions)
Conn Host                Address             Byte  Idle Conn Name
   1 Milwaukee           10.1.4.252             0     0 Milwaukee
*  2 NewYork             10.1.6.253             0     0 NewYork

Cincy# resume 1      (Resume connection 1 (see show session) to Milwaukee)
[Resuming connection 1 to milwaukee ... ]

Milwaukee>                          (User can type commands on Milwaukee)
Milwaukee>
Milwaukee>
! (Note: User pressed Ctrl-Shift-6 and then x, because the user wants to
!  go back to Cincy)

Cincy#         (WOW! User just pressed Enter and resumes the last Telnet)
 [Resuming connection 1 to milwaukee ... ]

Milwaukee>
Milwaukee>
Milwaukee>
                         (Note: User pressed Ctrl-Shift-6 and then x)
                         (Note: User is now back at router Cincy as a result)
Cincy# disconnect 1           (No more need to use Milwaukee  Telnet terminated!)
Closing connection to milwaukee [confirm]          (User presses Enter to confirm)
Cincy#
[Resuming connection 2 to NewYork ... ]
                  (Pressing Enter resumes most recently suspended active Telnet)

NewYork>
NewYork>
NewYork>
                         (Note: User pressed Ctrl-Shift-6 and then x)
                         (Note: User is now back at router Cincy as a result)
Cincy# disconnect 2                         (Done with New York, terminate Telnet)
Closing connection to NewYork [confirm]            (Just press Enter to confirm)
Cincy#
```

```
Yosemite# configure terminal
Yosemite(config)# interface Fa0/0
Yosemite(config-if)# ip address 10.2.1.1 255.255.255.0
Yosemite(config-if)# interface S0/1
Yosemite(config-if)# ip address 10.1.4.1 255.255.255.252
```

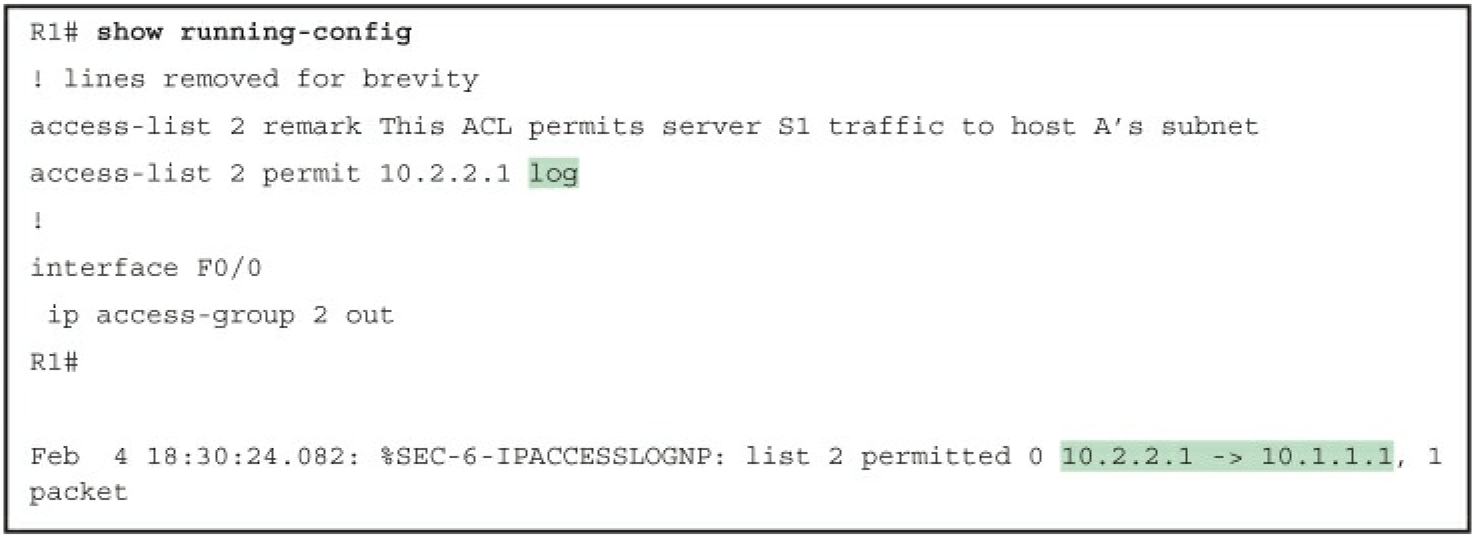
```
Albuquerque# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

     10.0.0.0/8 is variably subnetted, 14 subnets, 3 masks
D       10.2.1.0/24 [90/2172416] via 10.1.4.1, 00:00:34, Serial0/0
D       10.2.2.0/24 [90/2172416] via 10.1.4.1, 00:00:34, Serial0/0
D       10.2.3.0/24 [90/2172416] via 10.1.4.1, 00:00:34, Serial0/0
D       10.2.4.0/24 [90/2172416] via 10.1.4.1, 00:00:34, Serial0/0
D       10.3.4.0/24 [90/2172416] via 10.1.6.2, 00:00:56, Serial0/1
D       10.3.5.0/24 [90/2172416] via 10.1.6.2, 00:00:56, Serial0/1
D       10.3.6.0/24 [90/2172416] via 10.1.6.2, 00:00:56, Serial0/1
D       10.3.7.0/24 [90/2172416] via 10.1.6.2, 00:00:56, Serial0/1
C       10.1.1.0/24 is directly connected, FastEthernet0/0
L       10.1.1.1/32 is directly connected, FastEthernet0/0
C       10.1.6.0/30 is directly connected, Serial0/1
L       10.1.6.1/32 is directly connected, Serial0/1
C       10.1.4.0/30 is directly connected, Serial0/0
L       10.1.4.1/32 is directly connected, Serial0/0
```

```
! First, the before case
R1# show ip route rip
! (Legend lines omitted for brevity)
     10.0.0.0/8 is variably subnetted, 14 subnets, 3 masks
R       10.2.1.0/24 [120/1] via 10.1.4.2, 00:00:20, Serial0/0
R       10.2.2.0/24 [120/1] via 10.1.4.2, 00:00:20, Serial0/0
R       10.2.3.0/24 [120/1] via 10.1.4.2, 00:00:20, Serial0/0
R       10.2.4.0/24 [120/1] via 10.1.4.2, 00:00:20, Serial0/0
R       10.3.4.0/24 [120/1] via 10.1.6.3, 00:00:12, Serial0/1
R       10.3.5.0/24 [120/2] via 10.1.6.3, 00:00:12, Serial0/1
R       10.3.6.0/24 [120/3] via 10.1.6.3, 00:00:12, Serial0/1
R       10.3.7.0/24 [120/4] via 10.1.6.3, 00:00:12, Serial0/1


! Now, the after case.
R1# show ip route
! (Legend lines omitted for brevity)

     10.0.0.0/8 is variably subnetted, 11 subnets, 4 masks
R       10.2.1.0/24 [120/1] via 10.1.4.2, 00:00:20, Serial0/0
R       10.2.2.0/24 [120/1] via 10.1.4.2, 00:00:20, Serial0/0
R       10.2.3.0/24 [120/1] via 10.1.4.2, 00:00:20, Serial0/0
R       10.2.4.0/24 [120/1] via 10.1.4.2, 00:00:20, Serial0/0
R       10.3.0.0/16 [120/1] via 10.1.6.3, 00:00:04, Serial0/1
```

```
R2# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R2(config)# access-list 1 permit 10.1.1.1
R2(config)# access-list 1 deny 10.1.1.0 0.0.0.255
R2(config)# access-list 1 permit 10.0.0.0 0.255.255.255
R2(config)# interface S0/0/1
R2(config-if)# ip access-group 1 in
R2(config-if)# ^Z
R2# show running-config
! Lines omitted for brevity
access-list 1 permit 10.1.1.1
access-list 1 deny 10.1.1.0 0.0.0.255
access-list 1 permit 10.0.0.0 0.255.255.255
```

```
R2# show ip access-lists
Standard IP access list 1
    10 permit 10.1.1.1 (107 matches)
    20 deny   10.1.1.0, wildcard bits 0.0.0.255 (4 matches)
    30 permit 10.0.0.0, wildcard bits 0.255.255.255 (10 matches)
R2# show access-lists
Standard IP access list 1
    10 permit 10.1.1.1 (107 matches)
    20 deny   10.1.1.0, wildcard bits 0.0.0.255 (4 matches)
    30 permit 10.0.0.0, wildcard bits 0.255.255.255 (10 matches)
R2# show ip interface s0/0/1
Serial0/0/1 is up, line protocol is up
  Internet address is 10.1.2.2/24
  Broadcast address is 255.255.255.255
  Address determined by setup command
  MTU is 1500 bytes
  Helper address is not set
  Directed broadcast forwarding is disabled
  Multicast reserved groups joined: 224.0.0.9
  Outgoing access list is not set
  Inbound  access list is 1
! Lines omitted for brevity
```

```
access-list 2 remark This ACL permits server S1 traffic to host A’s subnet
access-list 2 permit 10.2.2.1
!
access-list 3 remark This ACL permits server S2 traffic to host C’s subnet
access-list 3 permit 10.2.2.2
!
interface F0/0
 ip access-group 2 out
!
interface F0/1
 ip access-group 3 out
```



```
R1# show running-config
! lines removed for brevity
access-list 2 remark This ACL permits server S1 traffic to host A's subnet
access-list 2 permit 10.2.2.1 log
!
interface F0/0
 ip access-group 2 out
R1#

Feb  4 18:30:24.082: %SEC-6-IPACCESSLOGNP: list 2 permitted 0 10.2.2.1 -> 10.1.1.1, 1
packet
```

```
R2# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R2(config)# access-list 21 permit 10.1.1.1 0.0.255.255
R2(config)# ^Z
R2#
R2# show ip access-lists
Standard IP access list 21
    10 permit 10.1.0.0, wildcard bits 0.0.255.255
```

```
interface Serial0
 ip address 172.16.12.1 255.255.255.0
 ip access-group 101 in
!
interface Serial1
 ip address 172.16.13.1 255.255.255.0
 ip access-group 101 in
!
access-list 101 remark Stop Bob to FTP servers, and Larry to Server1 web
access-list 101 deny tcp host 172.16.3.10 172.16.1.0 0.0.0.255 eq ftp
access-list 101 deny tcp host 172.16.2.10 host 172.16.1.100 eq www
access-list 101 permit ip any any
```

```
interface Ethernet0
 ip address 172.16.3.1 255.255.255.0
 ip access-group 103 in

access-list 103 remark deny Bob to FTP servers in subnet 172.16.1.0/24
access-list 103 deny tcp host 172.16.3.10 172.16.1.0 0.0.0.255 eq ftp
access-list 103 permit ip any any
```

```
interface ethernet 0
 ip access-group 110 in
!
access-list 110 deny ip host 10.1.2.1 10.1.1.0 0.0.0.255
access-list 110 deny ip 10.1.2.0 0.0.0.255 10.1.3.0 0.0.0.255
access-list 110 permit ip any any
```

```
Router# configure terminal
Enter configuration commands, one per line.  End with Ctrl-Z.
Router(config)# ip access-list extended barney
Router(config-ext-nacl)# permit tcp host 10.1.1.2 eq www any
Router(config-ext-nacl)# deny udp host 10.1.1.1 10.1.2.0 0.0.0.255
Router(config-ext-nacl)# deny ip 10.1.3.0 0.0.0.255 10.1.2.0 0.0.0.255
Router(config-ext-nacl)# deny ip 10.1.2.0 0.0.0.255 10.2.3.0 0.0.0.255
Router(config-ext-nacl)# permit ip any any
Router(config-ext-nacl)# interface serial1
Router(config-if)# ip access-group barney out
Router(config-if)# ^Z
Router# show running-config
Building configuration...

Current configuration:

! lines omitted for brevity

interface serial 1
 ip access-group barney out
!
ip access-list extended barney
 permit tcp host 10.1.1.2 eq www any
 deny   udp host 10.1.1.1 10.1.2.0 0.0.0.255
 deny   ip 10.1.3.0 0.0.0.255 10.1.2.0 0.0.0.255
 deny   ip 10.1.2.0 0.0.0.255 10.2.3.0 0.0.0.255
 permit ip any any
```

```
Router# configure terminal
Enter configuration commands, one per line.  End with Ctrl-Z.
Router(config)# ip access-list extended barney
Router(config-ext-nacl)# no deny ip 10.1.2.0 0.0.0.255 10.2.3.0 0.0.0.255
Router(config-ext-nacl)# ^Z
Router# show access-list

Extended IP access list barney
    10 permit tcp host 10.1.1.2 eq www any
    20 deny   udp host 10.1.1.1 10.1.2.0 0.0.0.255
    30 deny   ip 10.1.3.0 0.0.0.255 10.1.2.0 0.0.0.255
    50 permit ip any any
```

```
! Step 1: The 3-line Standard Numbered IP ACL is configured.
R1# configure terminal
Enter configuration commands, one per line.  End with Ctrl-Z.
R1(config)# ip access-list standard 24
R1(config-std-nacl)# permit 10.1.1.0 0.0.0.255
R1(config-std-nacl)# permit 10.1.2.0 0.0.0.255
R1(config-std-nacl)# permit 10.1.3.0 0.0.0.255

! Step 2: Displaying the ACL's contents, without leaving configuration mode.
R1(config-std-nacl)# do show ip access-list 24
Standard IP access list 24
    10 permit 10.1.1.0, wildcard bits 0.0.0.255
    20 permit 10.1.2.0, wildcard bits 0.0.0.255
    30 permit 10.1.3.0, wildcard bits 0.0.0.255

! Step 3: Still in ACL 24 configuration mode, the line with sequence number 20 is
deleted.
R1(config-std-nacl)# no 20

! Step 4: Displaying the ACL's contents again, without leaving configuration mode.
! Note that line number 20 is no longer listed.
R1(config-std-nacl)#do show ip access-list 24
Standard IP access list 24
    10 permit 10.1.1.0, wildcard bits 0.0.0.255
    30 permit 10.1.3.0, wildcard bits 0.0.0.255

! Step 5: Inserting a new first line in the ACL.
R1(config-std-nacl)# 5 deny 10.1.1.1

! Step 6: Displaying the ACL's contents one last time, with the new statement
!(sequence number 5) listed first.
R1(config-std-nacl)# do show ip access-list 24
Standard IP access list 24
     5 deny   10.1.1.1
    10 permit 10.1.1.0, wildcard bits 0.0.0.255
    30 permit 10.1.3.0, wildcard bits 0.0.0.255
```

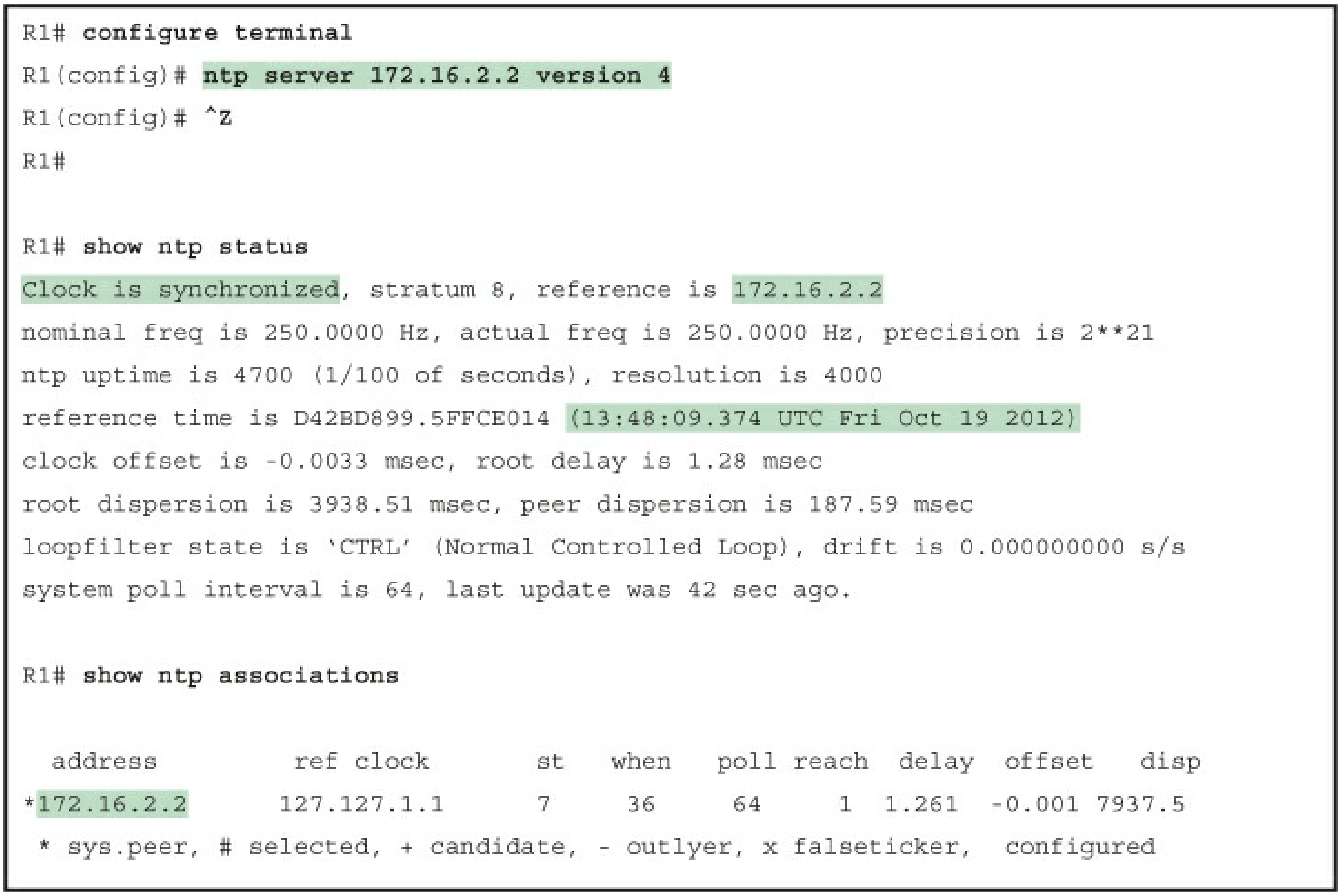
```
! Step 7: A configuration snippet for ACL 24.
R1# show running-config
! The only lines shown are the lines from ACL 24
access-list 24 deny   10.1.1.1
access-list 24 permit 10.1.1.0 0.0.0.255
access-list 24 permit 10.1.3.0 0.0.0.255

! Step 8: Adding a new access-list 24 global command
R1# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R1(config)# access-list 24 permit 10.1.4.0 0.0.0.255
R1(config)# ^Z

! Step 9: Displaying the ACL's contents again, with sequence numbers. Note that even
! the new statement has been automatically assigned a sequence number.
R1# show ip access-list 24
Standard IP access list 24
    5 deny   10.1.1.1
    10 permit 10.1.1.0, wildcard bits 0.0.0.255
    30 permit 10.1.3.0, wildcard bits 0.0.0.255
    40 permit 10.1.4.0, wildcard bits 0.0.0.255

! Step 10: The numbered ACL configuration remains in old-style configuration commands.
R1# show running-config
! The only lines shown are the lines from ACL 24
access-list 24 deny   10.1.1.1
access-list 24 permit 10.1.1.0 0.0.0.255
access-list 24 permit 10.1.3.0 0.0.0.255
access-list 24 permit 10.1.4.0 0.0.0.255
```

```
! Disable the HTTP service
R1(config)# no ip http server

! Disable small services, both TCP and UDP
R1(config)# no service tcp-small-servers
R1(config)# no service udp-small-servers

! Disable CDP on one interface only; no cdp run would disable
! CDP globally
R1(config)# interface gigabitEthernet 0/0
R1(config-if)# no cdp enable
R1(config-if)# ^Z
```

```
line vty 0 4
 login
 password cisco
 access-class 3 in
!
! Next command is a global command that matches IPv4 packets with
! a source address that begins with 10.1.1.
 access-list 3 permit 10.1.1.0 0.0.0.255
```

```
*Oct 19 13:38:37.568: %OSPF-5-ADJCHG: Process 1, Nbr 2.2.2.2 on Serial0/0/0 from FULL
to DOWN, Neighbor Down: Interface down or detached
*Oct 19 13:38:39.568: %LINK-5-CHANGED: Interface Serial0/0/0, changed state to admin-
istratively down
*Oct 19 13:38:40.568: %LINEPROTO-5-UPDOWN: Line protocol on Interface Serial0/0/0,
changed state to down
```

```
! These messages happened on router R2
Oct 19 09:44:09.027: %LINK-3-UPDOWN: Interface Serial0/0/1, changed state to down
Oct 19 09:44:09.027: %OSPF-5-ADJCHG: Process 1, Nbr 1.1.1.1 on Serial0/0/1 from FULL
to DOWN, Neighbor Down: Interface down or detached
Oct 19 09:44:10.027: %LINEPROTO-5-UPDOWN: Line protocol on Interface Serial0/0/1,
changed state to down
```



```
R1# configure terminal
R1(config)# ntp server 172.16.2.2 version 4
R1(config)# ^Z
R1#

R1# show ntp status
Clock is synchronized, stratum 8, reference is 172.16.2.2
nominal freq is 250.0000 Hz, actual freq is 250.0000 Hz, precision is 2**21
ntp uptime is 4700 (1/100 of seconds), resolution is 4000
reference time is D42BD899.5FFCE014 (13:48:09.374 UTC Fri Oct 19 2012)
clock offset is -0.0033 msec, root delay is 1.28 msec
root dispersion is 3938.51 msec, peer dispersion is 187.59 msec
loopfilter state is 'CTRL' (Normal Controlled Loop), drift is 0.000000000 s/s
system poll interval is 64, last update was 42 sec ago.

R1# show ntp associations

  address         ref clock       st   when   poll reach  delay  offset   disp
*172.16.2.2      127.127.1.1      7     36     64     1  1.261  -0.001 7937.5
 * sys.peer, # selected, + candidate, - outlyer, x falseticker,  configured
```

```
interface Ethernet0/0
 ip address 10.1.1.1 255.255.255.0
 ip nat inside
interface Serial0/0
 ip address 200.1.1.249 255.255.255.252
ip nat inside source list 1 interface Serial0/0
access-list 1 permit 10.1.1.0 0.0.0.255
```

```
-- Inside Source
access-list 1 pool fred refcount 2288
 pool fred: netmask 255.255.255.240
    start 200.1.1.1 end 200.1.1.7
    type generic, total addresses 7, allocated 7 (100%), misses 965
```

```
NAT# show running-config
!
! Lines omitted for brevity
!
interface GigabitEthernet0/0
 ip address 10.1.1.3 255.255.255.0
 ip nat inside
!
interface Serial0/0/0
 ip address 200.1.1.251 255.255.255.0
 ip nat outside
!
ip nat inside source static 10.1.1.2 200.1.1.2
ip nat inside source static 10.1.1.1 200.1.1.1

NAT# show ip nat translations
Pro Inside global      Inside local       Outside local      Outside global
--- 200.1.1.1          10.1.1.1           ---                ---
--- 200.1.1.2          10.1.1.2           ---                ---

NAT# show ip nat statistics
Total active translations: 2 (2 static, 0 dynamic; 0 extended)
Outside interfaces:
  Serial0/0/0
Inside interfaces:
  GigabitEthernet0/0
Hits: 100  Misses: 0
Expired translations: 0
Dynamic mappings:
```

```
NAT# show running-config
!
! Lines omitted for brevity
!
interface GigabitEthernet0/0
 ip address 10.1.1.3 255.255.255.0
 ip nat inside
!
interface Serial0/0/0
 ip address 200.1.1.251 255.255.255.0
 ip nat outside
!
ip nat pool fred 200.1.1.1 200.1.1.2 netmask 255.255.255.252
ip nat inside source list 1 pool fred
!
access-list 1 permit 10.1.1.2
access-list 1 permit 10.1.1.1
```

```
! The next command lists one empty line because no entries have been dynamically
! created yet.
NAT# show ip nat translations

NAT# show ip nat statistics
Total active translations: 0 (0 static, 0 dynamic; 0 extended)
Outside interfaces:
  Serial0/0
Inside interfaces:
  Ethernet0/0
Hits: 0  Misses: 0
CEF Translated packets: 0, CEF Punted packets: 0
Expired translations: 0
Dynamic mappings:
-- Inside Source
[id 1] access-list 1 pool fred refcount 0
 pool fred: netmask 255.255.255.252
    start 200.1.1.1 end 200.1.1.2
    type generic, total addresses 2, allocated 0 (0%), misses 0

Total doors: 0
Appl doors: 0
Normal doors: 0
Queued Packets: 0
```

```
NAT# show ip nat translations
Pro Inside global      Inside local       Outside local      Outside global
--- 200.1.1.1          10.1.1.1           ---                ---

NAT# show ip nat statistics
Total active translations: 1 (0 static, 1 dynamic; 0 extended)
Outside interfaces:
  Serial0/0
Inside interfaces:
  Ethernet0/0
Hits: 69  Misses: 1
Expired translations: 0
Dynamic mappings:
-- Inside Source
access-list 1 pool fred refcount 1
 pool fred: netmask 255.255.255.252
    start 200.1.1.1 end 200.1.1.2
    type generic, total addresses 2, allocated 1 (50%), misses 0
```

```
! Host 10.1.1.1 current uses inside global 200.1.1.1
NAT# show ip nat translations
Pro Inside global      Inside local       Outside local      Outside global
--- 200.1.1.1          10.1.1.1           ---                ---
NAT# clear ip nat translation *

!
! telnet from 10.1.1.2 to 170.1.1.1 happened next; not shown
!
! Now host 10.1.1.2 uses inside global 200.1.1.1

NAT# show ip nat translations
Pro Inside global      Inside local       Outside local      Outside global
--- 200.1.1.1          10.1.1.2           ---                ---
!
! Telnet from 10.1.1.1 to 170.1.1.1 happened next; not shown
!
NAT# debug ip nat
IP NAT debugging is on

Oct 20 19:23:03.263: NAT*: s=10.1.1.1->200.1.1.2, d=170.1.1.1 [348]
Oct 20 19:23:03.267: NAT*: s=170.1.1.1, d=200.1.1.1->10.1.1.1 [348]
Oct 20 19:23:03.464: NAT*: s=10.1.1.1->200.1.1.2, d=170.1.1.1 [349]
Oct 20 19:23:03.568: NAT*: s=170.1.1.1, d=200.1.1.1->10.1.1.1 [349]
```

```
NAT# show running-config
!
! Lines Omitted for Brevity
!
interface GigabitEthernet0/0
 ip address 10.1.1.3 255.255.255.0
 ip nat inside
!
interface Serial0/0/0
 ip address 200.1.1.249 255.255.255.252
 ip nat outside
!
ip nat inside source list 1 interface Serial0/0/0 overload
!
access-list 1 permit 10.1.1.2
access-list 1 permit 10.1.1.1
!

NAT# show ip nat translations
Pro Inside global      Inside local        Outside local      Outside global
tcp 200.1.1.249:3212   10.1.1.1:3212       170.1.1.1:23       170.1.1.1:23
tcp 200.1.1.249:3213   10.1.1.2:3213       170.1.1.1:23       170.1.1.1:23
tcp 200.1.1.249:38913  10.1.1.2:38913      170.1.1.1:23       170.1.1.1:23
NAT# show ip nat statistics
Total active translations: 3 (0 static, 3 dynamic; 3 extended)
Outside interfaces:
  Serial0/0/0
Inside interfaces:
  GigabitEthernet0/0
Hits: 103  Misses: 3
Expired translations: 0
Dynamic mappings:
-- Inside Source
access-list 1 interface Serial0/0/0 refcount 3
```

```
ipv6 unicast-routing
!
interface GigabitEthernet0/0
 ipv6 address 2001:DB8:1111:1::1/64
!
interface Serial0/0/0
 ipv6 address 2001:0db8:1111:0002:0000:0000:0000:0001/64
```

```
! The first interface is in subnet 1
R1# show ipv6 interface GigabitEthernet 0/0
GigabitEthernet0/0 is up, line protocol is up
  IPv6 is enabled, link-local address is FE80::1FF:FE01:101
  No Virtual link-local address(es):
  Description: LAN at Site 1
  Global unicast address(es):
    2001:DB8:1111:1::1, subnet is 2001:DB8:1111:1::/64
  Joined group address(es):
    FF02::1
    FF02::2
    FF02::A
    FF02::1:FF00:1
    FF02::1:FF01:101
  MTU is 1500 bytes
  ICMP error messages limited to one every 100 milliseconds
  ICMP redirects are enabled
  ICMP unreachables are sent
  ND DAD is enabled, number of DAD attempts: 1
  ND reachable time is 30000 milliseconds (using 30000)
  ND advertised reachable time is 0 (unspecified)
  ND advertised retransmit interval is 0 (unspecified)
  ND router advertisements are sent every 200 seconds
  ND router advertisements live for 1800 seconds
  ND advertised default router preference is Medium
  Hosts use stateless autoconfig for addresses.
```

```
R1# show ipv6 interface S0/0/0
Serial0/0/0 is up, line protocol is up
  IPv6 is enabled, link-local address is FE80::1FF:FE01:101
  No Virtual link-local address(es):
  Description: link to R2
  Global unicast address(es):
    2001:DB8:1111:2::1, subnet is 2001:DB8:1111:2::/64
  Joined group address(es):
    FF02::1
    FF02::2
    FF02::A
    FF02::1:FF00:1
    FF02::1:FF01:101
  MTU is 1500 bytes
! Lines omitted for brevity

R1# show ipv6 interface brief
GigabitEthernet0/0     [up/up]
    FE80::1FF:FE01:101
    2001:DB8:1111:1::1
GigabitEthernet0/1     [administratively down/down]
    unassigned
Serial0/0/0            [up/up]
    FE80::1FF:FE01:101
    2001:DB8:1111:2::1
Serial0/0/1            [administratively down/down]
    unassigned
```

```
R1# show ipv6 route connected
IPv6 Routing Table - default - 5 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, R - RIP, I1 - ISIS L1, I2 - ISIS L2
       IA - ISIS interarea, IS - ISIS summary, D - EIGRP, EX - EIGRP external
       ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
C   2001:DB8:1111:1::/64 [0/0]
     via GigabitEthernet0/0, directly connected
C   2001:DB8:1111:2::/64 [0/0]
     via Serial0/0/0, directly connected
```

```
! The next commands are on router R1
ipv6 unicast-routing
!
! The ipv6 address command now lists the a prefix
interface GigabitEthernet0/0
 ipv6 address 2001:DB8:1111:1::/64 eui-64
!
interface Serial0/0/0
 ipv6 address 2001:DB8:1111:2::/64 eui-64

R1# show ipv6 interface brief
GigabitEthernet0/0     [up/up]
    FE80::1FF:FE01:101
    2001:DB8:1111:1:0:1FF:FE01:101
GigabitEthernet0/1     [administratively down/down]
    unassigned
Serial0/0/0            [up/up]
    FE80::1FF:FE01:101
    2001:DB8:1111:2:0:1FF:FE01:101
Serial0/0/1            [administratively down/down]
    unassigned
```

```
! This interface uses DHCP to learn its IPv6 address
interface FastEthernet0/0
 ipv6 address dhcp
!
! This interface uses SLAAC to learn its IPv6 address
interface FastEthernet0/1
 ipv6 address autoconfig
```

```
R1# show ipv6 interface brief
GigabitEthernet0/0      [up/up]
    FE80::1FF:FE01:101
    2001:DB8:1111:1:0:1FF:FE01:101
GigabitEthernet0/1      [administratively down/down]
    unassigned
Serial0/0/0             [up/up]
    FE80::1FF:FE01:101
    2001:DB8:1111:2:0:1FF:FE01:101
Serial0/0/1             [administratively down/down]
    unassigned
```

```
R1# show ipv6 interface GigabitEthernet 0/0
GigabitEthernet0/0 is up, line protocol is up
  IPv6 is enabled, link-local address is FE80::1FF:FE01:101
  No Virtual link-local address(es):
  Description: LAN at Site 1
  Global unicast address(es):
    2001:DB8:1111:1::1, subnet is 2001:DB8:1111:1::/64
  Joined group address(es):
    FF02::1
    FF02::2
    FF02::A
    FF02::1:FF00:1
    FF02::1:FF01:101
  ! Lines omitted for brevity
```

```
interface GigabitEthernet0/0
 ipv6 dhcp relay destination 2001:DB8:1111:3::8

R1# show ipv6 interface g0/0
GigabitEthernet0/0 is up, line protocol is up
  IPv6 is enabled, link-local address is FE80::FF:FE00:1
  No Virtual link-local address(es):
  Description: to SW1 port F0/1
  Global unicast address(es):
    2001:DB8:1111:1::1, subnet is 2001:DB8:1111:1::/64 [EUI]
  Joined group address(es):
    FF02::1
    FF02::2
    FF02::A
    FF02::1:2
    FF02::1:FF00:1
! Lines omitted for brevity
```

```
WOair$ ifconfig en0
en0: flags=8863<UP,BROADCAST,SMART,RUNNING,SIMPLEX,MULTICAST> mtu 1500
         ether 10:93:e9:06:a4:b6
         inet6 fe80::1293:e9ff:fe06:a4b6%en0 prefixlen 64 scopeid 0x4
         inet 192.168.1.163 netmask 0xffffff00 broadcast 192.168.1.255
         inet6 2001:db8:1111:1:1293:e9ff:fe06:a4b6 prefixlen 64 autoconf
         inet6 2001:db8:1111:1:50c0:2cf5:a699:d7ba prefixlen 64 autoconf temporary
         media: autoselect
         status: active
```

```
Master@PC1:$ ping6 2001:db8:1111:1::1
PING 2001:db8:1111:1::1 (2001:db8:1111:1::1) 56 data bytes
64 bytes from 2001:db8:1111:1::11: icmp_seq=1 ttl=64 time=1.26 ms
64 bytes from 2001:db8:1111:1::11: icmp_seq=2 ttl=64 time=1.15 ms
^C
--- 2001:db8:1111:1::1 ping statistics ---
2 packets transmitted, 2 received, 0% packet loss, time 1001 ms
rtt min/avg/max/mdev = 1.156/1.210/1.263/0.062 ms

Master@PC1:$ ping6 2001:db8:1111:3::22
PING 2001:db8:1111:3::22 ( 2001:db8:1111:3::22) 56 data bytes
64 bytes from 2001:db8:1111:3::22: icmp_seq=1 ttl=64 time=2.33 ms
64 bytes from 2001:db8:1111:3::22: icmp_seq=2 ttl=64 time=2.59 ms
64 bytes from 2001:db8:1111:3::22: icmp_seq=3 ttl=64 time=2.03 ms
^C
--- 2001:db8:1111:3::22 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2003 ms
rtt min/avg/max/mdev = 2.039/2.321/2.591/0.225 ms

! An IPv4 ping next, for comparison - ping of PC2 from PC1
Master@PC1:$ ping 10.1.3.22
PING 10.1.3.22 (10.1.3.22) 56 data bytes
64 bytes from 10.1.3.22: icmp_seq=1 ttl=64 time=2.45 ms
64 bytes from 10.1.3.22: icmp_seq=2 ttl=64 time=2.55 ms
64 bytes from 10.1.3.22: icmp_seq=3 ttl=64 time=2.14 ms
^C
--- 10.1.3.22 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2014 ms
rtt min/avg/max/mdev = 2.04/2.318/2.604/0.224 ms
```

```
Master@PC1:$ traceroute6 2001:db8:1111:3::22
traceroute to 2001:db8:1111:3::22 (2001:db8:1111:3::22) from 2001:db8:1111:1::11,
   30 hops max, 24 byte packets
1  2001:db8:1111:1::1 (2001:db8:1111:1::1)  0.794 ms  0.648 ms  0.604 ms
2  2001:db8:1111:2::2 (2001:db8:1111:2::2)  1.606 ms  1.49 ms  1.497 ms
3  2001:db8:1111:3::22 (2001:db8:1111:3::22)  2.038 ms  1.911 ms  1.899 ms
```

```
R1# ping
Protocol [ip]: ipv6
Target IPv6 address: 2001:db8:1111:3::22
Repeat count [5]:
Datagram size [100]:
Timeout in seconds [2]:
Extended commands? [no]: yes
Source address or interface: GigabitEthernet0/0
UDP protocol? [no]:
Verbose? [no]:
Precedence [0]:
DSCP [0]:
Include hop by hop option? [no]:
Include destination option? [no]:
Sweep range of sizes? [no]:
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 2001:DB8:1111:3::22, timeout is 2 seconds:
Packet sent with a source address of 2001:DB8:1111:1::1
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 0/1/4 ms

R1# traceroute 2001:db8:1111:3::22
Type escape sequence to abort.
Tracing the route to 2001:DB8:1111:3::22

  1 2001:DB8:1111:2::2 4 msec 0 msec 0 msec
  2 2001:DB8:1111:3::22 0 msec 4 msec 0 msec
```

```
R2# show ipv6 neighbors
IPv6 Address                                Age Link-layer Addr State Interface
FE80::11FF:FE11:1111                          0 0200.1111.1111  STALE Gi0/0
FE80::22FF:FE22:2222                          1 0200.2222.2222  STALE Gi0/0
2001:DB8:1111:3::22                           0 0200.2222.2222  REACH Gi0/0
FE80::FF:FE00:3333                            1 0200.0000.3333  DELAY Gi0/0
2001:DB8:1111:3::33                           0 0200.1111.1111  REACH Gi0/0
2001:DB8:1111:3::3                            0 0200.0000.3333  REACH Gi0/0
```

```
! No routers listed by this command on R1
R1# show ipv6 routers
R1#
```

```
! The next command happens on R2 - one router (R3) listed
R2# show ipv6 routers
Router FE80::FF:FE00:3333 on GigabitEthernet0/0, last update 0 min
  Hops 64, Lifetime 1800 sec, AddrFlag=0, OtherFlag=0, MTU=1500
  HomeAgentFlag=0, Preference=Medium
  Reachable time 0 (unspecified), Retransmit time 0 (unspecified)
  Prefix 2001:DB8:1111:3::/64 onlink autoconfig
    Valid lifetime 2592000, preferred lifetime 604800
```

```
WOAir$ ndp -an
Neighbor                         Linklayer Address  Netif Expire    St  Flgs Prbs
::1                              (incomplete)         lo0 permanent R
2001:db8:1111:1::1               5c:d9:98:59:b3:fc    en0 1s        D   R
2001:db8:1111:1:1293:e9ff:fe06:a4b6 10:93:e9:6:a4:b6 en0 5s        R
```

```
ipv6 unicast-routing
!
interface serial0/0/0
  ipv6 address 2001:db8:1111:4::1/64
!
interface serial0/0/1
  ipv6 address 2001:db8:1111:5::1/64
!
interface gigabitethernet0/0
  ipv6 address 2001:db8:1111:1::1/64
```

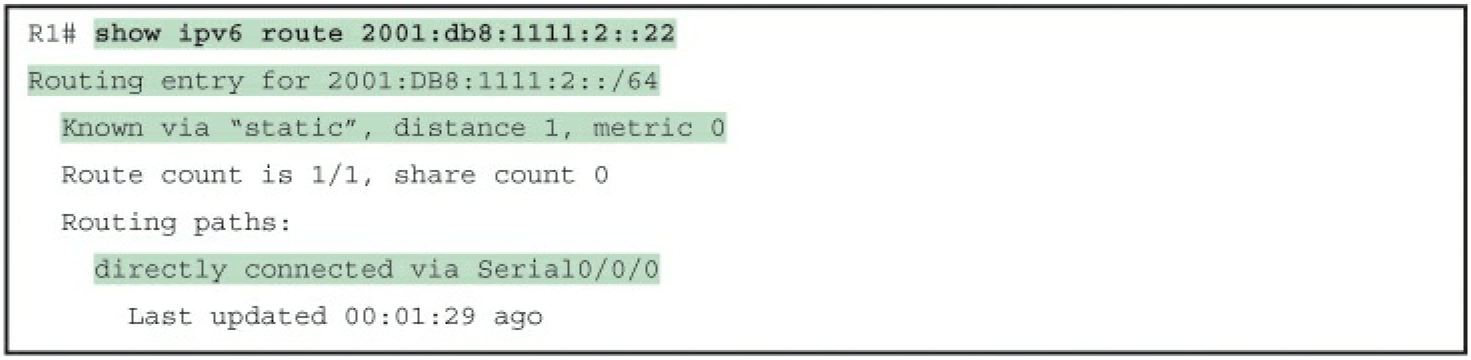
```
R1# show ipv6 route
IPv6 Routing Table - default - 7 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, R - RIP, I1 - ISIS L1, I2 - ISIS L2
       IA - ISIS interarea, IS - ISIS summary, D - EIGRP, EX - EIGRP external
       ND - Neighbor Discovery, l - LISP
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
C   2001:DB8:1111:1::/64 [0/0]
     via GigabitEthernet0/0, directly connected
L   2001:DB8:1111:1::1/128 [0/0]
     via GigabitEthernet0/0, receive
C   2001:DB8:1111:4::/64 [0/0]
     via Serial0/0/0, directly connected
L   2001:DB8:1111:4::1/128 [0/0]
     via Serial0/0/0, receive
C   2001:DB8:1111:5::/64 [0/0]
     via Serial0/0/1, directly connected
L   2001:DB8:1111:5::1/128 [0/0]
     via Serial0/0/1, receive
L   FF00::/8 [0/0]
     via Null0, receive
```

```
R1# show ipv6 route local
! Legend omitted for brevity

L   2001:DB8:1111:1::1/128 [0/0]
     via GigabitEthernet0/0, receive
L   2001:DB8:1111:4::1/128 [0/0]
     via Serial0/0/0, receive
L   2001:DB8:1111:5::1/128 [0/0]
     via Serial0/0/1, receive
L   FF00::/8 [0/0]
     via Null0, receive
```

```
! Static route on router R1
R1(config)# ipv6 route 2001:db8:1111:2::/64 s0/0/0
```

```
! Static route on router R2
R2(config)# ipv6 route 2001:db8:1111:1::/64 s0/0/1
```

```
R1# show ipv6 route static
! Legend omitted for brevity
S   2001:DB8:1111:2::/64 [1/0]
     via Serial0/0/0, directly connected
```



```
R1# show ipv6 route 2001:db8:1111:2::22
Routing entry for 2001:DB8:1111:2::/64
  Known via "static", distance 1, metric 0
  Route count is 1/1, share count 0
  Routing paths:
    directly connected via Serial0/0/0
      Last updated 00:01:29 ago
```

```
! The first command is on router R1, listing R2's global unicast address
R1(config)# ipv6 route 2001:db8:1111:2::/64 2001:DB8:1111:4::2
```

```
! The next command is on router R2, listing R1's global unicast address
R2(config)# ipv6 route 2001:db8:1111:1::/64 2001:db8:1111:4::1
```

```
R1# show ipv6 route static
! Legend omitted for brevity
S   2001:DB8:1111:2::/64 [1/0]
     via 2001:DB8:1111:4::2

R1# show ipv6 route 2001:db8:1111:2::22/64
Routing entry for 2001:DB8:1111:2::/64
  Known via “static”, distance 1, metric 0
  Backup from “ospf 1 [110]”
  Route count is 1/1, share count 0
  Routing paths:
    2001:DB8:1111:4::2
      Last updated 00:07:43 ago
```

```
! The first command is on router R1, listing R2's link-local address
R1(config)# ipv6 route 2001:db8:1111:2::/64 S0/0/0 FE80::FF:FE00:2
```

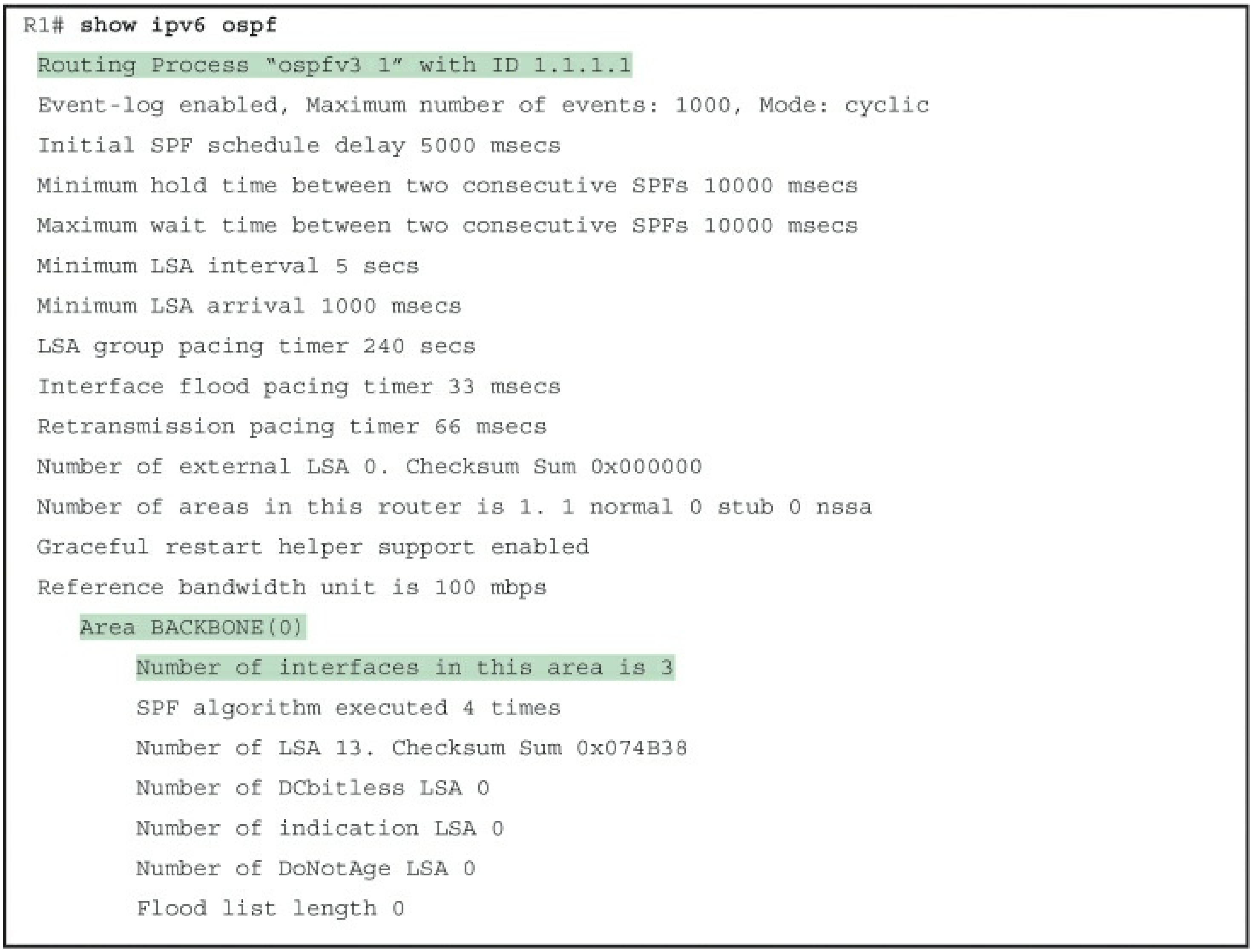
```
! The next command is on router R2, listing R1's link-local address
R2(config)# ipv6 route 2001:db8:1111:1::/64 S0/0/1 FE80::FF:FE00:1
```

```
R1# show ipv6 route static
! Legend omitted for brevity

S   2001:DB8:1111:2::/64 [1/0]
     via FE80::FF:FE00:2, Serial0/0/0

R1# show ipv6 route 2001:db8:1111:2::22
Routing entry for 2001:DB8:1111:2::/64
  Known via “static”, distance 1, metric 0
  Backup from “ospf 1 [110]”
  Route count is 1/1, share count 0
  Routing paths:
    FE80::FF:FE00:2, Serial0/0/0
      Last updated 00:08:10 ago
```

```
!Forward out B1's S0/0/1 local interface…
B1(config)# ipv6 route ::/0 S0/0/1
```

```
B1# show ipv6 route static
IPv6 Routing Table - default - 10 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, R - RIP, I1 - ISIS L1, I2 - ISIS L2
       IA - ISIS interarea, IS - ISIS summary, D - EIGRP, EX - EIGRP external
       ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
S   ::/0 [1/0]
     via Serial0/0/1, directly connected
```

```
R1# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R1(config)# ipv6 router ospf 1
Jan  4 21:03:50.622: %OSPFv3-4-NORTRID: OSPFv3 process 1 could not pick a router-id,
please configure manually
R1(config-rtr)# router-id 1.1.1.1
R1(config-rtr)#
R1(config-rtr)# interface serial0/0/0
R1(config-if)# ipv6 ospf 1 area 0
R1(config-if)# interface serial0/0/1
R1(config-if)# ipv6 ospf 1 area 0
R1(config-if)# interface GigabitEthernet0/0
R1(config-if)# ipv6 ospf 1 area 0
R1(config-if)# end
R1#
```



```
R1# show ipv6 ospf
 Routing Process "ospfv3 1" with ID 1.1.1.1
 Event-log enabled, Maximum number of events: 1000, Mode: cyclic
 Initial SPF schedule delay 5000 msecs
 Minimum hold time between two consecutive SPFs 10000 msecs
 Maximum wait time between two consecutive SPFs 10000 msecs
 Minimum LSA interval 5 secs
 Minimum LSA arrival 1000 msecs
 LSA group pacing timer 240 secs
 Interface flood pacing timer 33 msecs
 Retransmission pacing timer 66 msecs
 Number of external LSA 0. Checksum Sum 0x000000
 Number of areas in this router is 1. 1 normal 0 stub 0 nssa
 Graceful restart helper support enabled
 Reference bandwidth unit is 100 mbps
    Area BACKBONE(0)
        Number of interfaces in this area is 3
        SPF algorithm executed 4 times
        Number of LSA 13. Checksum Sum 0x074B38
        Number of DCbitless LSA 0
        Number of indication LSA 0
        Number of DoNotAge LSA 0
        Flood list length 0
```

```
R1# show ipv6 ospf interface brief
Interface    PID   Area              Intf ID    Cost  State Nbrs F/C
Gi0/0        1     0                 3          1     DR    0/0
Se0/0/1      1     0                 7          64    P2P   1/1
Se0/0/0      1     0                 6          64    P2P   1/1

R1# show ipv6 protocols
IPv6 Routing Protocol is "connected"
IPv6 Routing Protocol is "ND"
IPv6 Routing Protocol is "ospf 1"
  Interfaces (Area 0):
    GigabitEthernet0/0
    Serial0/0/1
    Serial0/0/0
  Redistribution:
    None
```

```
! The first command is from router R1, listing R2 and R3
R1# show ipv6 ospf neighbor

Neighbor ID     Pri   State           Dead Time   Interface ID    Interface
3.3.3.3           0   FULL/  -        00:00:39    6               Serial0/0/1
2.2.2.2           0   FULL/  -        00:00:31    7               Serial0/0/0
```

```
! The next command is from router R2, listing R1 and R3
R2# show ipv6 ospf neighbor

Neighbor ID     Pri   State           Dead Time   Interface ID    Interface
1.1.1.1           0   FULL/  -        00:00:39    6               Serial0/0/1
3.3.3.3           1   FULL/DR         00:00:33    3               GigabitEthernet0/0
```

```
R2# show ipv6 ospf database

            OSPFv3 Router with ID (2.2.2.2) (Process ID 2)

                Router Link States (Area 0)

ADV Router       Age         Seq#        Fragment ID  Link count  Bits
 1.1.1.1         452         0x80000002  0            2           None
 2.2.2.2         456         0x80000004  0            2           None
 3.3.3.3         457         0x80000005  0            2           None

! Lines omitted for brevity
```

```
R2# show ipv6 route ospf
IPv6 Routing Table - default - 9 entries
! Legend omitted for brevity

O   2001:DB8:1111:1::/64 [110/65]
     via FE80::FF:FE00:1, Serial0/0/1
O   2001:DB8:1111:5::/64 [110/65]
     via FE80::FF:FE00:3, GigabitEthernet0/0
```

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Elan Beer, CCIE No. 1837, is a senior consultant and Cisco instructor specializing in data center architecture and multiprotocol network design. For the past 25 years, Elan has designed networks and trained thousands of industry experts in data center architecture, routing, and switching. Elan has been instrumental in large-scale professional service efforts designing and troubleshooting internetworks, performing Data center and network audits, and assisting clients with their short-and long-term design objectives. Elan has a global perspective of network architectures via his international clientele. Elan has used his expertise to design and troubleshoot data centers and internetworks in Malaysia, North America, Europe, Australia, Africa, China, and the Middle East. Most recently, Elan has been focused on data center design, configuration, and troubleshooting as well as service provider technologies. In 1993, Elan was among the first to obtain Cisco's Certified System Instructor (CCSI) certification, and in 1996, he was among the first to attain Cisco System's highest technical certification, the Cisco Certified Internetworking Expert. Since then, Elan has been involved in numerous large-scale data center and telecommunications networking projects worldwide.

Dedication

In memory of Carcel Lanier (C.L.) Odom: Dad’s Pop, Poppa, wearing khakis, quiet, tearing down the old house (one board at a time), tagging along at the cow sales barn, walking the property, and napping during the Sunday morning sermon.

Acknowledgments

Although published as a first edition for various reasons, this book (and the companion *Cisco CCENT/CCNA ICND1 100-101 Exam Cert Guide*) represents the seventh book in a long line of Cisco Press books focused on helping people pass the CCENT and CCNA R/S certifications. Given the long history, many people have worked on these books from their inception back in 1998. To those many people who have touched these books over these past 15 years—technical edits, development, copy edits, project editing, proofing, indexing, managing the production process, interior design, cover design, marketing, and all the other details that happen to get these books out the door—thanks so much for playing a role in this CCENT/CCNA franchise.

Many of the contributors to the previous editions returned to work on creating these new editions, including Development Editor Drew Cupp. Drew kept all the details straight, with my frequent changes to the outlines and titles, keeping the sequencing on track, while still doing his primary job: keeping the text and features clear and consistent throughout the book. Thanks, Drew, for walking me through the development.

Contributing author Anthony Sequeira did a nice job stepping in on the network management part of the book. Anthony was a perfect fit, given his interest in management protocols and tools, and his writing experience and his great teaching skills (with enthusiasm!). Thanks for helping make this book complete and doing such a great job.

As for technical editors, Elan Beer did his normal job. That is, he did his usual amazing job of doing every part of the technical edit job well, from finding the tiny little cross-reference errors that lie pages apart, to anticipating how readers might misunderstand certain phrasing, to being all over the details of every technical feature. Fantastic job as usual; thanks, Elan.

Brett Bartow again served as executive editor of the book, as he has almost since the beginning of these titles. When my family has asked me over the years about Brett's role with these books, the best single word definition is *teammate*. Brett may be employed at Pearson Education, but he is always working with me and for me, watching out for the business end of the books and finding ways to make the publisher/author relationship work seamlessly. Thanks for another great ride through these books, Brett!

Word docs go in, and out come these beautiful finished products. Thanks to Sandra Schroeder, Tonya Simpson, and all the production team for working through the magic that takes those Word docs and makes the beautiful finished product. From fixing all my grammar, crummy word choices, passive-voice sentences, and then pulling the design and layout together, they do it all. Thanks for putting it all together and making it look easy. And Tonya, managing the details through several process steps for roughly 100 elements between the pair of CCNA books in a short timeframe: Wow, thanks for the amazing juggling act! And thanks especially for the attention to detail.

The figures for these books go through a little different process than they do for other books. Together we invested a large amount of labor in updating the figures for these books, both for the design, the number of figures, and for the color versions of the figures for the electronic versions of the books. A special thanks goes out to Laura Robbins for working with me on the color and design standards early in the process. Also, thanks to Mike Tanamachi for drawing all the figures so well (and then redrawing them every time I changed my mind about something).

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A special thank you to you readers who write in with suggestions, possible errors, and especially those of you who post online at the Cisco Learning Network. Without question, the comments I receive directly and overhear by participating at CLN made this edition a better book.

Thanks to my wife, Kris. Book schedules have a bigger impact than I would like, but you always make it work. Thanks to my daughter, Hannah, for all the great study/work breaks on some of these busy schooldays. And thanks to Jesus Christ, for this opportunity to write.

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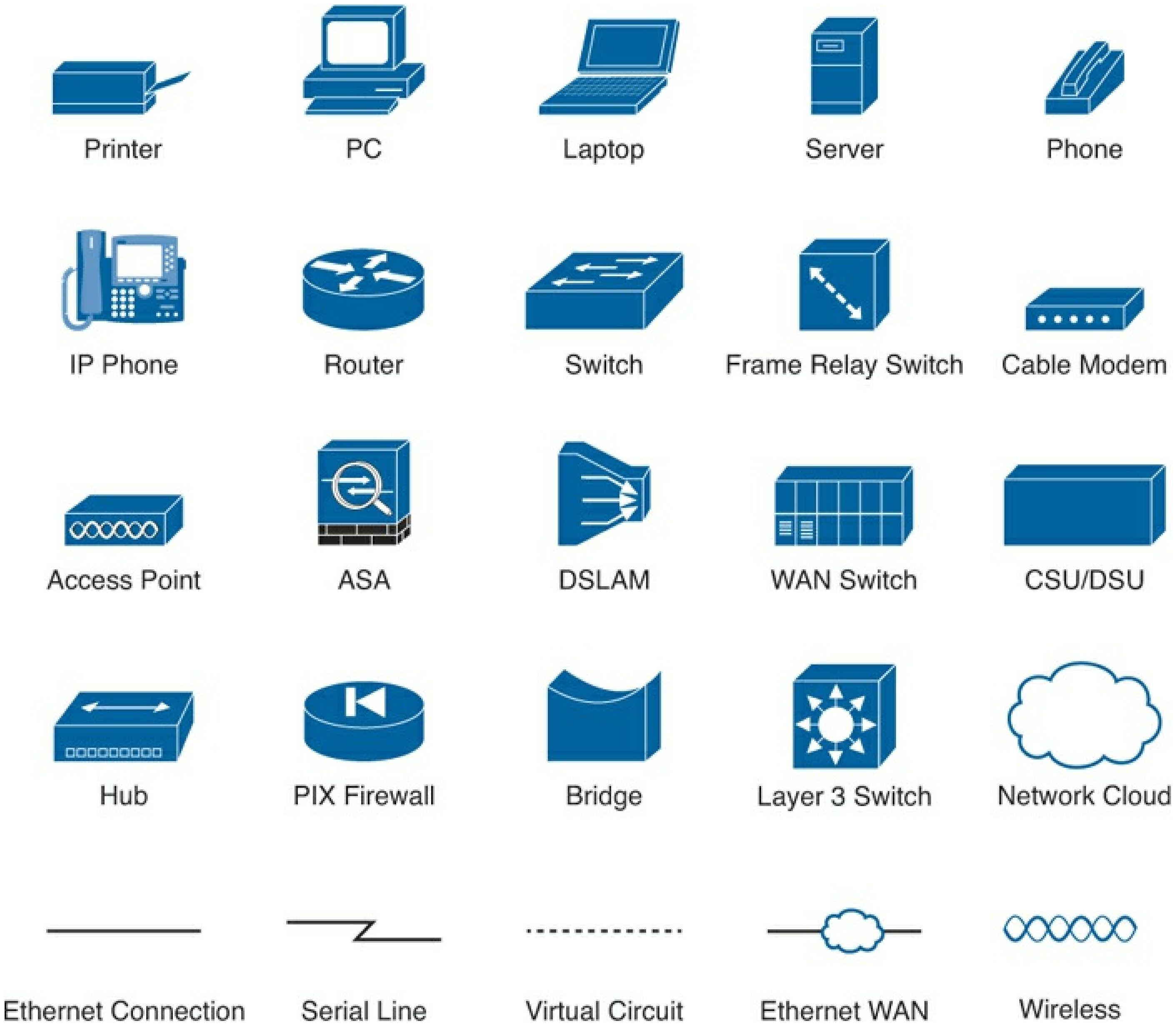

Printer
PC
Laptop
Server
Phone
IP Phone
Router
Switch
Frame Relay Switch
Cable Modem
Access Point
ASA
DSLAM
WAN Switch
CSU/DSU
Hub
PIX Firewall
Bridge
Layer 3 Switch
Network Cloud
Ethernet Connection
Serial Line
Virtual Circuit
Ethernet WAN
Wireless

Command Syntax Conventions

The conventions used to present command syntax in this book are the same conventions used in the IOS Command Reference. The Command Reference describes these conventions as follows: ■ **Boldface** indicates commands and keywords that are entered literally as shown. In actual configuration examples and output (not general command syntax), boldface indicates commands that are manually input by the user (such as a **show** command).

- *Italic* indicates arguments for which you supply actual values.
- Vertical bars (|) separate alternative, mutually exclusive elements.
- Square brackets ([ ]) indicate an optional element.
- Braces ({ }) indicate a required choice.
- Braces within brackets ([{ }]) indicate a required choice within an optional element.

Introduction

About the Exams

Congratulations! If you're reading far enough to look at this book's Introduction, you've probably already decided to go for your Cisco certification. If you want to succeed as a technical person in the networking industry at all, you need to know Cisco. Cisco has a ridiculously high market share in the router and switch marketplace, with more than 80 percent market share in some markets. In many geographies and markets around the world, networking equals Cisco. If you want to be taken seriously as a network engineer, Cisco certification makes perfect sense.

The Exams That Help You Achieve CCENT and CCNA

Cisco announced changes to the CCENT and CCNA Routing and Switching certifications, and the related 100-101 ICND1, 200-101 ICND2, and 200-120 CCNA exams, early in the year 2013. For those of you who understand how the old Cisco ICND1, ICND2, and CCNA exams worked, the structure remains the same. For those of you new to Cisco certifications, this introduction begins by introducing the basics.

Most everyone new to Cisco certifications begins with either CCENT or CCNA Routing and Switching. CCENT certification requires knowledge and skills on about half as much material as does CCNA Routing and Switching, so CCENT is the easier first step.

The CCENT certification requires a single step: pass the ICND1 exam. Simple enough.

The CCNA Routing and Switching certification gives you two options, as shown in Figure I-1: pass both the ICND1 and ICND2 exams, or just pass the CCNA exam. (Note that there is no separate certification for passing the ICND2 exam.)

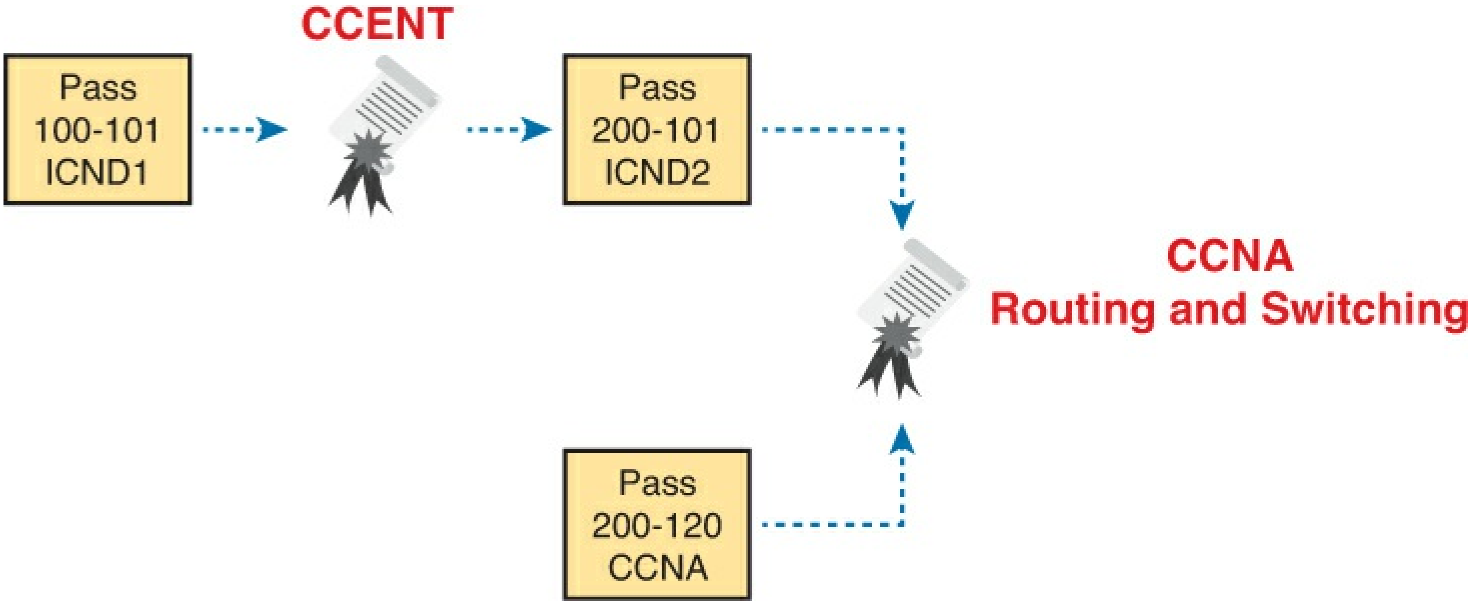


Figure I-1. Cisco Entry-Level Certifications and Exams

As you can see, although you can obtain the CCENT certification by taking the ICND1 exam, you do not have to be CCENT certified before you get your CCNA Routing and Switching certification. You can choose to take the CCNA exam and bypass the CCENT certification.

As for the topics themselves, the ICND1 and ICND2 exams cover different topics (but with some overlap required). For example, ICND1 covers the basics of the Open Shortest Path First (OSPF) routing protocol. ICND2 covers more detail about OSPF, but to discuss those additional details, ICND2 must rely on the parts of OSPF included in ICND1. Many topics in ICND2 build on topics in ICND1, causing some overlap.

The CCNA exam covers all the topics in both ICND1 and ICND2, no more, no less.

Types of Questions on the Exams

The ICND1, ICND2, and CCNA exams all follow the same general format. At the testing center, you sit in a quiet room with a PC. Before the exam timer begins, you have a chance to do a few other tasks on the PC; for instance, you can take a sample quiz just to get accustomed to the PC and the testing engine. Anyone who has user-level skills in getting around a PC should have no problems with the testing environment.

Once the exam starts, the screen shows you question after question. The questions usually fall into one of the following categories:

- Multiple choice, single answer
- Multiple choice, multiple answer
- Testlet
- Drag-and-drop
- Simulated lab (sim)
- Simlet

The first three items in the list are all multiple choice questions. The multiple choice format simply requires that you point and click a circle beside the correct answer(s). Cisco traditionally tells you how many answers you need to choose, and the testing software prevents you from choosing too many answers. The testlet style gives you one larger scenario statement, with multiple different multiple choice questions about that one scenario.

Drag-and-drop questions require you to move some items around on the GUI. You left-click and hold, move a button or icon to another area, and release the clicker to place the object somewhere else—usually into a list. So, for some questions, to answer the question correctly, you might need to put a list of five things in the proper order.

The last two types both use a network simulator to ask questions. Interestingly, the two types actually allow Cisco to assess two very different skills. First, sim questions generally describe a problem, and your task is to configure one or more routers and switches to fix the problem. The exam then grades the question based on the configuration you changed or added.

The simlet questions may well be the most difficult style of question on the exams. Simlet questions also use a network simulator, but instead of you answering the question by changing the configuration, the question includes one or more multiple choice questions. The questions require that you use the simulator to examine the current behavior of a network, interpreting the output of any **show** commands that you can remember to answer the question. Whereas sim questions require you to troubleshoot problems related to a configuration, simlets require you to both analyze both working and broken networks, correlating **show** command output with your knowledge of networking theory and configuration commands.

You can watch and even experiment with these command types using the Cisco Exam Tutorial. To find the Cisco Certification Exam Tutorial, go to http://www.cisco.com and search for "exam tutorial."

What's on the CCNA Exams?

Ever since I was in grade school, whenever the teacher announced that we were having a test soon, someone would always ask, "What's on the test?" Even in college, people would try to get more information about what would be on the exams. At heart, the goal is to know what to study hard, what to study a little, and what to not study at all.

Cisco tells the world the topics on each of their exams. Cisco wants the public to know both the variety of topics, and an idea about the kinds of knowledge and skills required for each topic, for every Cisco certification exam. To that end, Cisco publishes a set of exam topics for each exam.

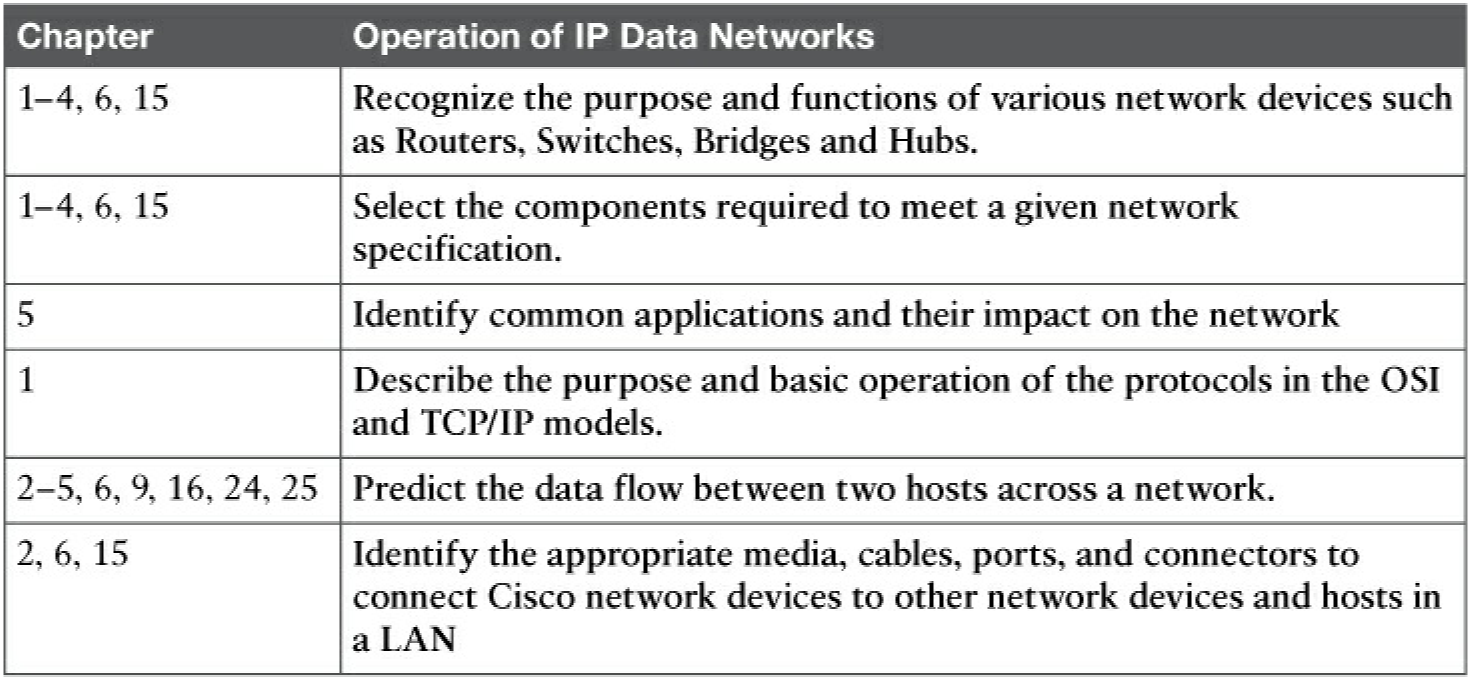
Many Cisco exam topics list both a networking topic plus an important verb. The verb tells us to what degree the topic must be understood and what skills are required. The topic also implies the kinds of skills required for that topic. For example, one topic might start with "Describe...," another with "Configure...," another with "Verify...," and another might begin with "Troubleshoot...." That last topic has the highest required skill level, because to troubleshoot you must understand the topic, be able to configure it (to see what's wrong with the configuration), and verify it (to find the root cause of the problem). By listing the topics and skill level, Cisco helps us all prepare for its exams. Although the exam topics are helpful, keep in mind that Cisco adds a disclaimer that the posted exam topics for all of its certification exams are *guidelines*. Cisco makes the effort to keep the exam questions within the confines of the stated exam topics, and I know from talking to those involved that every question is analyzed for whether it fits within the stated exam topics.

ICND1 Exam Topics

Tables I-1 through I-7 lists the exam topics for the ICND1 exam. Following those tables, Tables I-8 through I-12 list the exam topics for ICND2. These tables note the book chapters in which each exam topic is covered.

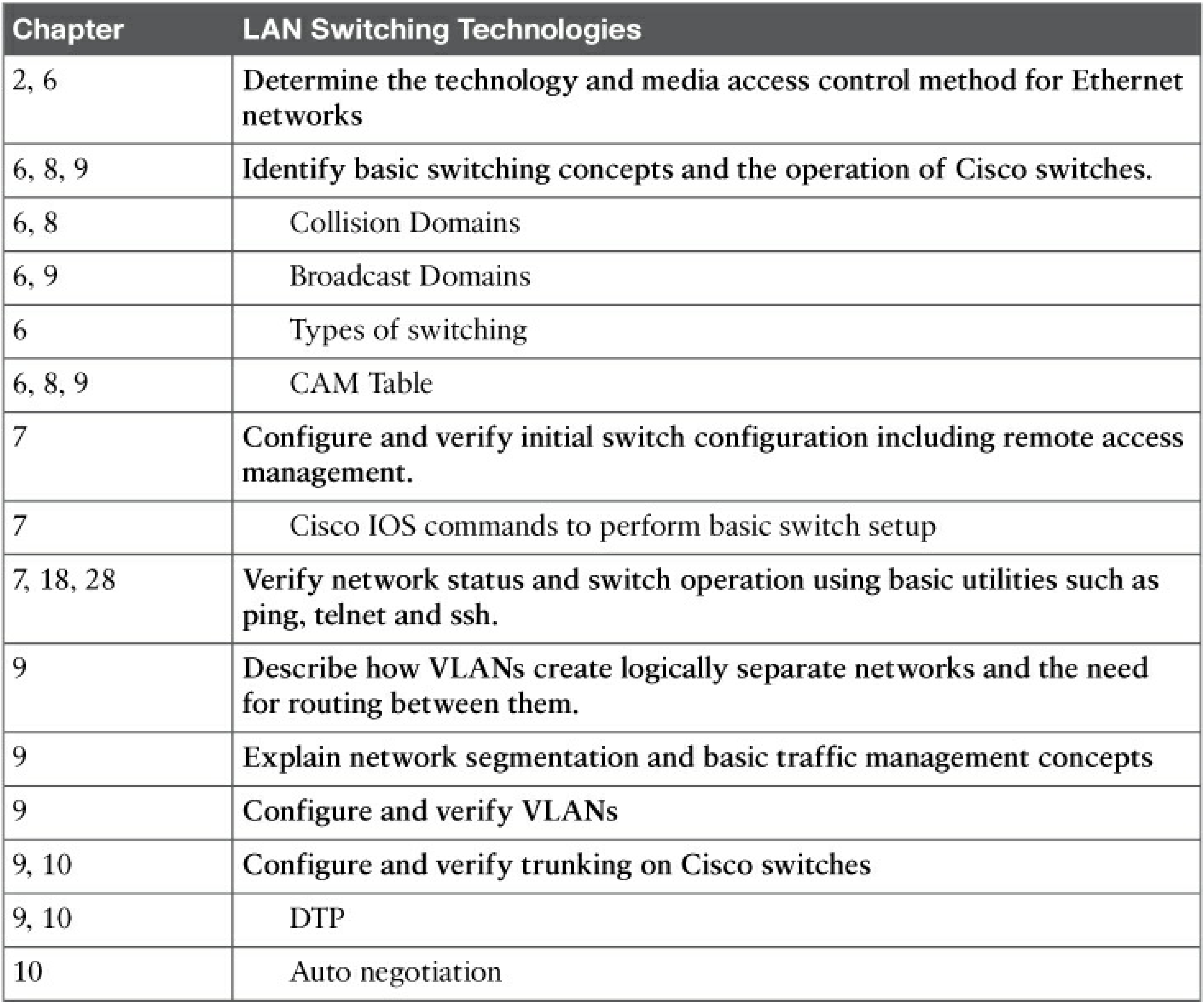
Note that the tables follow Cisco's organization of topics, by both grouping similar topics and listing subtopics. The subtopics simply give more specific terms and concepts to provide more detail about some exam topics. The tables show the main topics in bold and the subtopics as indented text inside the tables.

Table I-1. ICND1 Exam Topics: Operation of IP Data Networks



Chapter	Operation of IP Data Networks
1–4, 6, 15	Recognize the purpose and functions of various network devices such as Routers, Switches, Bridges and Hubs.
1–4, 6, 15	Select the components required to meet a given network specification.
5	Identify common applications and their impact on the network
1	Describe the purpose and basic operation of the protocols in the OSI and TCP/IP models.
2–5, 6, 9, 16, 24, 25	Predict the data flow between two hosts across a network.
2, 6, 15	Identify the appropriate media, cables, ports, and connectors to connect Cisco network devices to other network devices and hosts in a LAN

Table I-2. ICND1 Exam Topics: LAN Switching Technologies

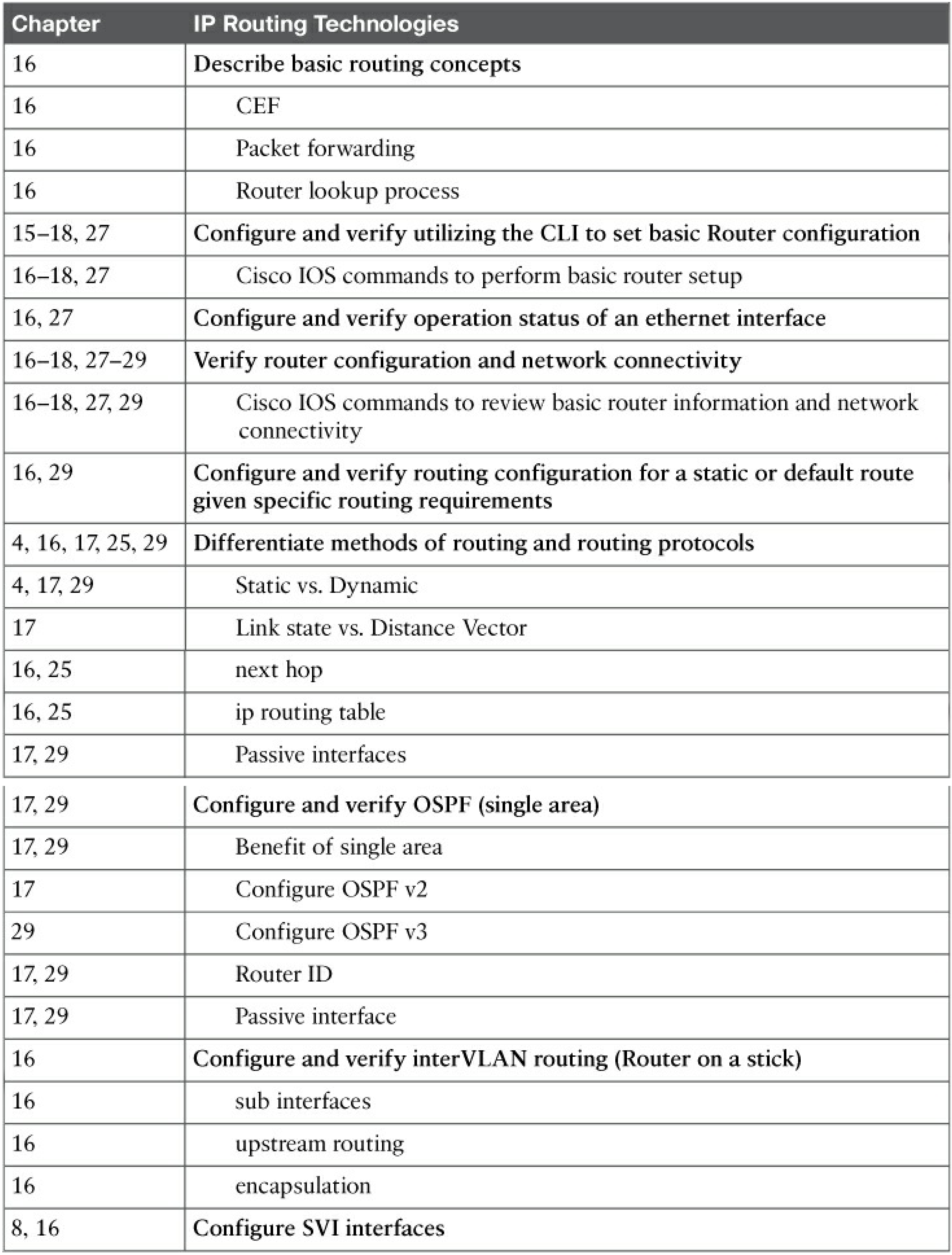


Chapter	LAN Switching Technologies
2, 6	**Determine the technology and media access control method for Ethernet networks**
6, 8, 9	**Identify basic switching concepts and the operation of Cisco switches.**
6, 8	Collision Domains
6, 9	Broadcast Domains
6	Types of switching
6, 8, 9	CAM Table
7	**Configure and verify initial switch configuration including remote access management.**
7	Cisco IOS commands to perform basic switch setup
7, 18, 28	**Verify network status and switch operation using basic utilities such as ping, telnet and ssh.**
9	**Describe how VLANs create logically separate networks and the need for routing between them.**
9	**Explain network segmentation and basic traffic management concepts**
9	**Configure and verify VLANs**
9, 10	**Configure and verify trunking on Cisco switches**
9, 10	DTP
10	Auto negotiation

Table I-3. ICND1 Exam Topics: IP Addressing (IPv4/IPv6)

Chapter	IP Addressing (IPv4/IPv6)
11	**Describe the operation and necessity of using private and public IP addresses for IPv4 addressing**
25, 26	**Identify the appropriate IPv6 addressing scheme to satisfy addressing requirements in a LAN/WAN environment.**
11, 19, 20, 21	**Identify the appropriate IPv4 addressing scheme using VLSM and summarization to satisfy addressing requirements in a LAN/WAN environment.**
27, 28, 29	**Describe the technological requirements for running IPv6 in conjunction with IPv4 such as dual stack**
25–28	**Describe IPv6 addresses**
25, 26	Global unicast
27	Multicast
27	Link local
26	Unique local
27	eui 64
28	autoconfiguration

Table I-4. ICND1 Exam Topics: IP Routing Technologies

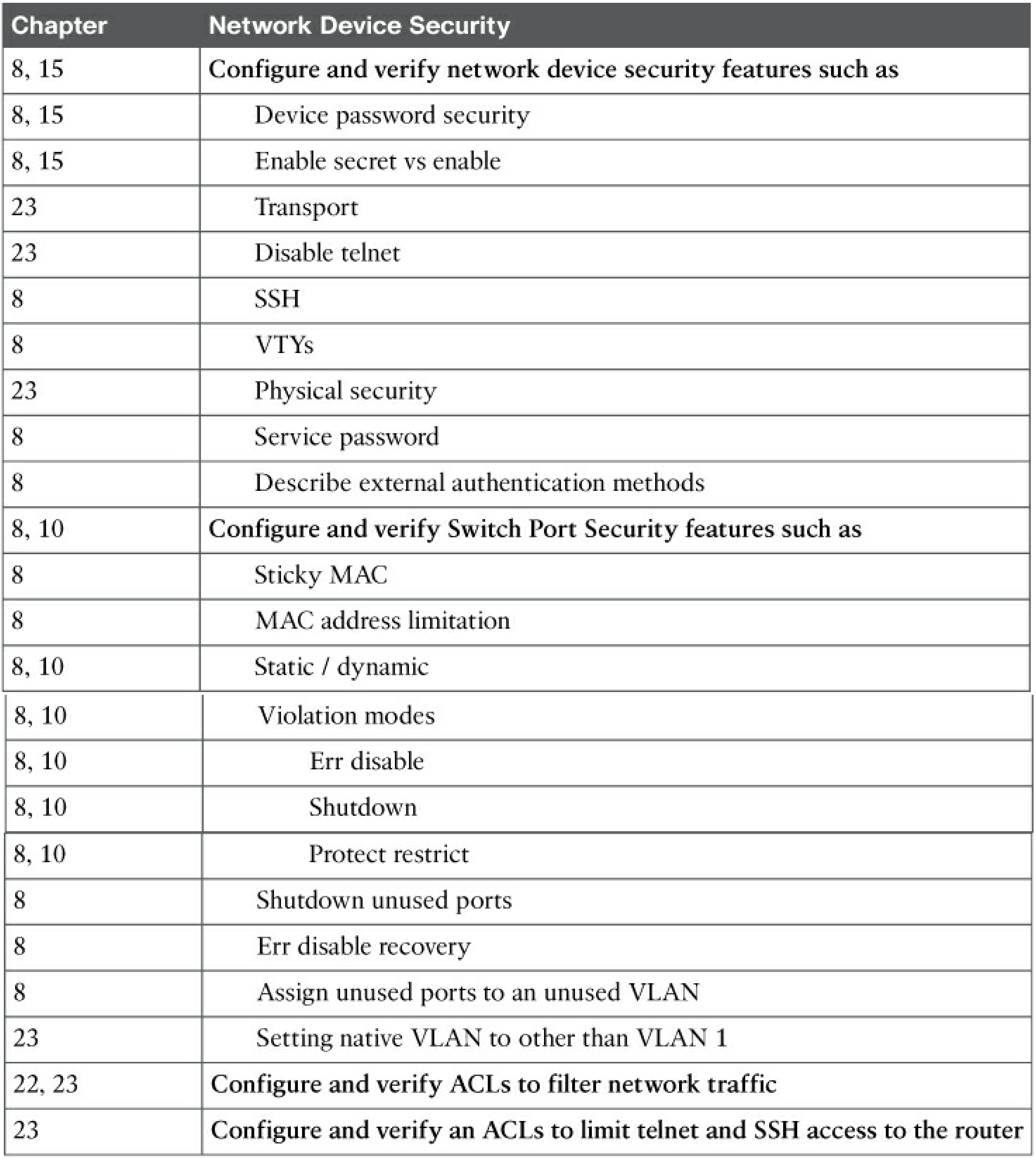


Chapter	IP Routing Technologies
16	**Describe basic routing concepts**
16	CEF
16	Packet forwarding
16	Router lookup process
15–18, 27	**Configure and verify utilizing the CLI to set basic Router configuration**
16–18, 27	Cisco IOS commands to perform basic router setup
16, 27	**Configure and verify operation status of an ethernet interface**
16–18, 27–29	**Verify router configuration and network connectivity**
16–18, 27, 29	Cisco IOS commands to review basic router information and network connectivity
16, 29	**Configure and verify routing configuration for a static or default route given specific routing requirements**
4, 16, 17, 25, 29	**Differentiate methods of routing and routing protocols**
4, 17, 29	Static vs. Dynamic
17	Link state vs. Distance Vector
16, 25	next hop
16, 25	ip routing table
17, 29	Passive interfaces
17, 29	**Configure and verify OSPF (single area)**
17, 29	Benefit of single area
17	Configure OSPF v2
29	Configure OSPF v3
17, 29	Router ID
17, 29	Passive interface
16	**Configure and verify interVLAN routing (Router on a stick)**
16	sub interfaces
16	upstream routing
16	encapsulation
8, 16	**Configure SVI interfaces**

Table I-5. ICND1 Exam Topics: IP Services

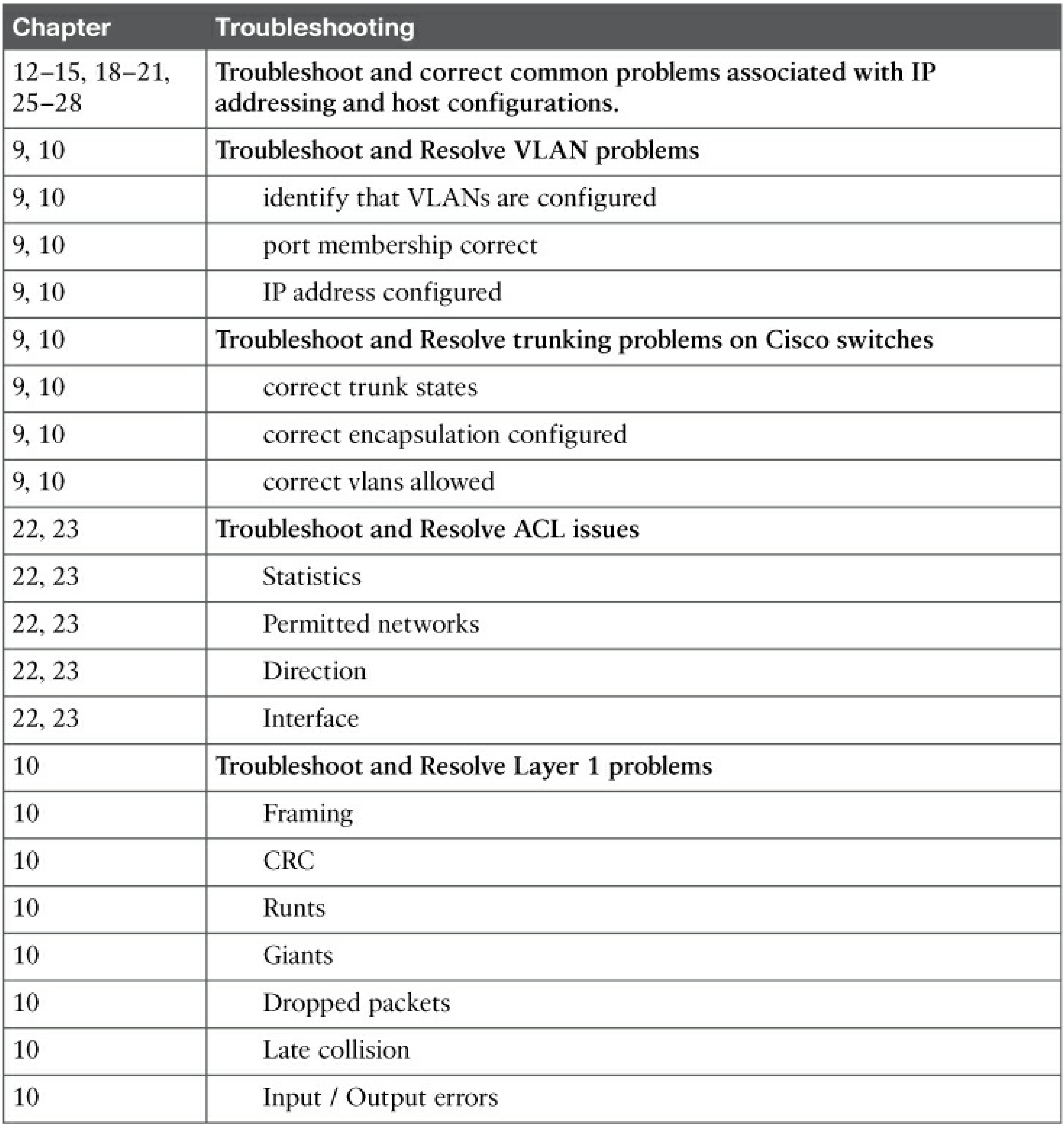
Chapter	IP Services
18, 28	**Configure and verify DHCP (IOS Router)**
18, 28	configuring router interfaces to use DHCP
18	DHCP options
18	excluded addresses
18	lease time
22, 23	**Describe the types, features, and applications of ACLs**
22	Standard
23	Sequence numbers
23	Editing
23	Extended
23	Named
22, 23	Numbered
22	Log option
22, 23	**Configure and verify ACLs in a network environment**
23	Named
22, 23	Numbered
22	Log option
24	**Identify the basic operation of NAT**
24	Purpose
24	Pool
24	Static
24	1 to 1
24	Overloading
24	Source addressing
24	One way NAT
24	**Configure and verify NAT for given network requirements**
23	**Configure and verify NTP as a client**

Table I-6. ICND1 Exam Topics: Network Device Security



Chapter	Network Device Security
8, 15	**Configure and verify network device security features such as**
8, 15	Device password security
8, 15	Enable secret vs enable
23	Transport
23	Disable telnet
8	SSH
8	VTYs
23	Physical security
8	Service password
8	Describe external authentication methods
8, 10	**Configure and verify Switch Port Security features such as**
8	Sticky MAC
8	MAC address limitation
8, 10	Static / dynamic
8, 10	Violation modes
8, 10	Err disable
8, 10	Shutdown
8, 10	Protect restrict
8	Shutdown unused ports
8	Err disable recovery
8	Assign unused ports to an unused VLAN
23	Setting native VLAN to other than VLAN 1
22, 23	**Configure and verify ACLs to filter network traffic**
23	**Configure and verify an ACLs to limit telnet and SSH access to the router**

Table I-7. ICND1 Exam Topics: Troubleshooting



Chapter	Troubleshooting
12–15, 18–21, 25–28	**Troubleshoot and correct common problems associated with IP addressing and host configurations.**
9, 10	**Troubleshoot and Resolve VLAN problems**
9, 10	identify that VLANs are configured
9, 10	port membership correct
9, 10	IP address configured
9, 10	**Troubleshoot and Resolve trunking problems on Cisco switches**
9, 10	correct trunk states
9, 10	correct encapsulation configured
9, 10	correct vlans allowed
22, 23	**Troubleshoot and Resolve ACL issues**
22, 23	Statistics
22, 23	Permitted networks
22, 23	Direction
22, 23	Interface
10	**Troubleshoot and Resolve Layer 1 problems**
10	Framing
10	CRC
10	Runts
10	Giants
10	Dropped packets
10	Late collision
10	Input / Output errors

ICND2 Exam Topics

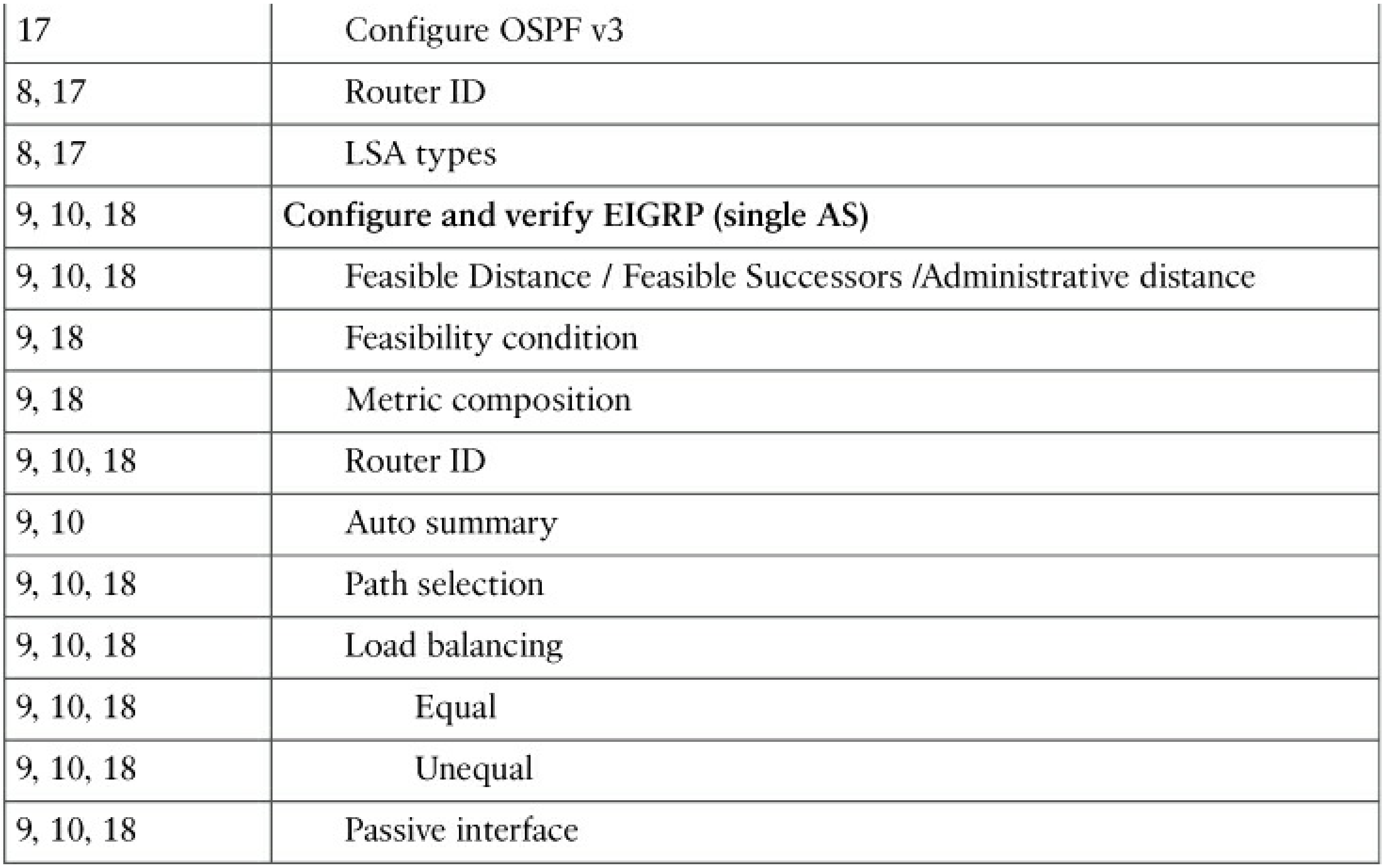
Tables I-8 through I-12 list the exam topics for ICND2. These tables note the book chapters in which each exam topic is covered. Note that each table covers a main exam topic. Cisco released further information about each topic to several sublevels of hierarchy. In this table, those sublevels are indented to indicate the topic above them they are related to.

Table I-8. ICND2 Exam Topics: LAN Switching Technologies

Chapters	LAN Switching Technologies
1	**Identify enhanced switching technologies**
1	RSTP
1	PVSTP
1	Etherchannels
1, 2	**Configure and verify PVSTP operation**
1, 2	describe root bridge election
2	spanning tree mode

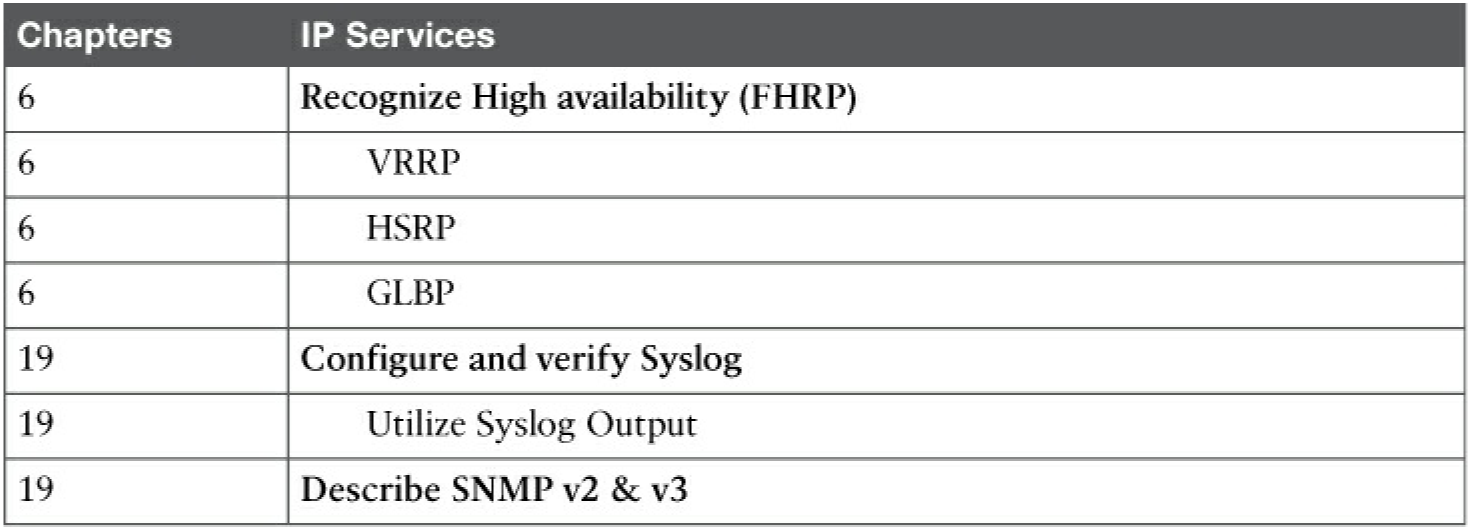
Table I-9. ICND2 Exam Topics, IP Routing Technologies

Chapters	IP Routing Technologies
20	**Describe the boot process of Cisco IOS routers**
20	POST
20	Router bootup process
12	**Configure and verify operation status of a Serial interface.**
20, 21	**Manage Cisco IOS Files**
20	Boot preferences
20	Cisco IOS image(s)
21	Licensing
21	Show license
21	Change license
8–11, 16–18	**Differentiate methods of routing and routing protocols**
8	Administrative distance
9	split horizon
8, 9, 17, 18	metric
8, 9, 17, 18	next hop
8, 17	**Configure and verify OSPF (single area)**
8, 11, 17	neighbor adjacencies
8, 11, 17	OSPF states
8, 17	Discuss Multi area
8	Configure OSPF v2



17	Configure OSPF v3
8, 17	Router ID
8, 17	LSA types
9, 10, 18	**Configure and verify EIGRP (single AS)**
9, 10, 18	Feasible Distance / Feasible Successors /Administrative distance
9, 18	Feasibility condition
9, 18	Metric composition
9, 10, 18	Router ID
9, 10	Auto summary
9, 10, 18	Path selection
9, 10, 18	Load balancing
9, 10, 18	Equal
9, 10, 18	Unequal
9, 10, 18	Passive interface

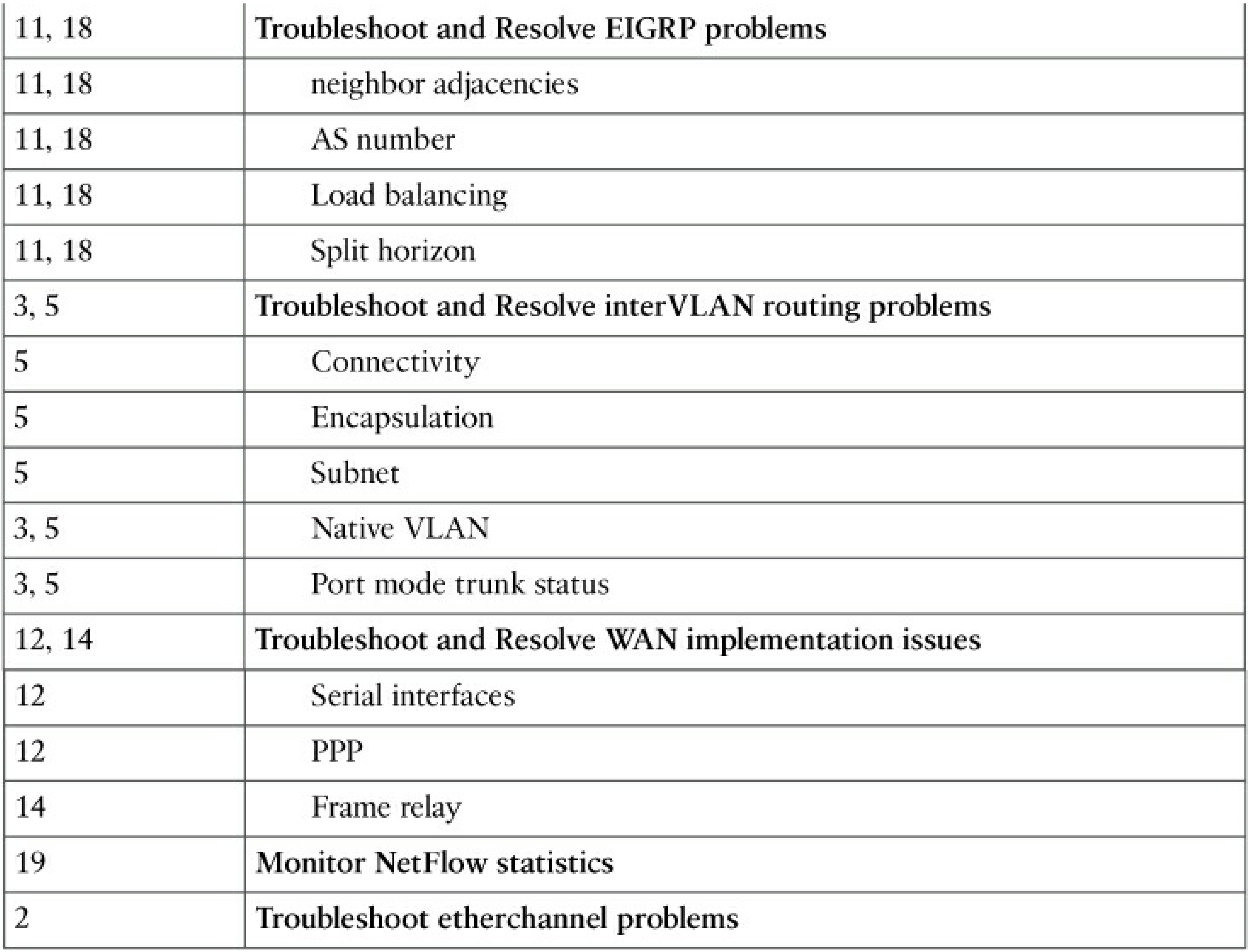
Table I-10. ICND2 Exam Topics, IP Services



Chapters	IP Services
6	**Recognize High availability (FHRP)**
6	VRRP
6	HSRP
6	GLBP
19	**Configure and verify Syslog**
19	Utilize Syslog Output
19	**Describe SNMP v2 & v3**

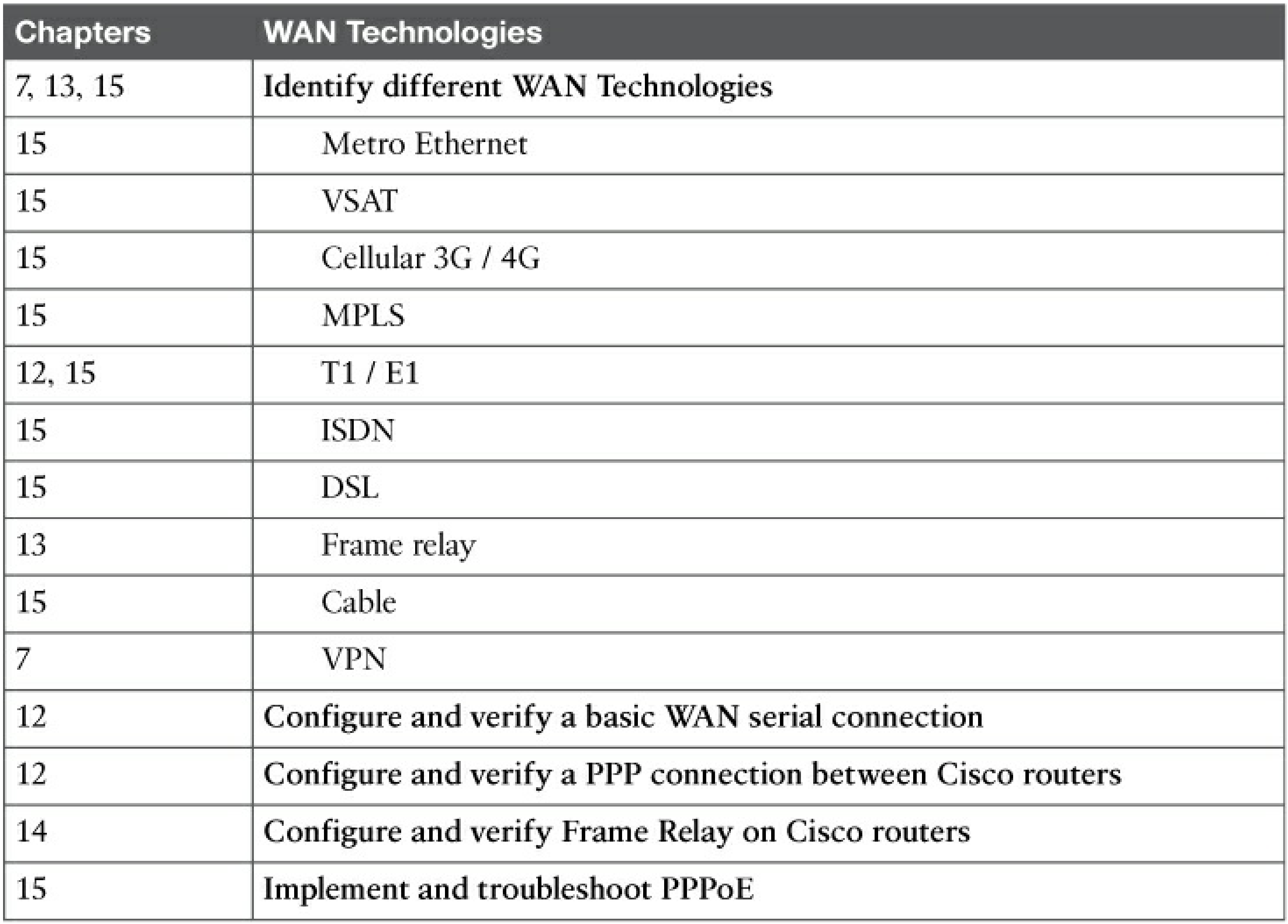
Table I-11. ICND2 Exam Topics, Troubleshooting

Chapters	Troubleshooting
3–5, 16	**Identify and correct common network problems**
19	**Utilize netflow data**
2	**Troubleshoot and Resolve Spanning Tree operation issues**
2	root switch
2	priority
2	mode is correct
2	port states
4, 5, 16	**Troubleshoot and Resolve routing issues**
4, 5, 16	routing is enabled
4, 5, 16	routing table is correct
4, 5, 16	correct path selection
11, 17	**Troubleshoot and Resolve OSPF problems**
11, 17	neighbor adjacencies
11, 17	Hello and Dead timers
11, 17	OSPF area
11, 17	Interface MTU
11, 17	Network types
11, 17	Neighbor states
11, 17	OSPF topology database



11, 18	**Troubleshoot and Resolve EIGRP problems**
11, 18	neighbor adjacencies
11, 18	AS number
11, 18	Load balancing
11, 18	Split horizon
3, 5	**Troubleshoot and Resolve interVLAN routing problems**
5	Connectivity
5	Encapsulation
5	Subnet
3, 5	Native VLAN
3, 5	Port mode trunk status
12, 14	**Troubleshoot and Resolve WAN implementation issues**
12	Serial interfaces
12	PPP
14	Frame relay
19	**Monitor NetFlow statistics**
2	**Troubleshoot etherchannel problems**

Table I-12. ICND2 Exam Topics: WAN Technologies



Chapters	WAN Technologies
7, 13, 15	**Identify different WAN Technologies**
15	Metro Ethernet
15	VSAT
15	Cellular 3G / 4G
15	MPLS
12, 15	T1 / E1
15	ISDN
15	DSL
13	Frame relay
15	Cable
7	VPN
12	**Configure and verify a basic WAN serial connection**
12	**Configure and verify a PPP connection between Cisco routers**
14	**Configure and verify Frame Relay on Cisco routers**
15	**Implement and troubleshoot PPPoE**

CCNA Exam Topics

The 200-120 CCNA exam actually covers everything from both the ICND1 and ICND2 exams, at least based on the published exam topics. As of publication, the CCNA exam topics include all topics in Tables I-1 through I-12. In short, CCNA = ICND1 + ICND2.

> **Note**
>
> Because it is possible that the exam topics may change over time, it might be worth the time to double-check the exam topics as listed on the Cisco website (http://www.cisco.com/go/ccent and http://www.cisco.com/go/ccna). If Cisco does happen to add exam topics at a later date, note that Appendix B, "ICND2 Exam Updates," describes how to go to http://www.ciscopress.com and download additional information about those newly added topics.

About the Book

This book discusses the content and skills needed to pass the 200-101 ICND2 exam. That content also serves as basically the second half of the CCNA content, with this book's companion title, the *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*, discussing the first half of the content.

Each of these books uses the same kinds of book features, so if you are reading both this book and the ICND1 book, you do not need to read the Introduction to the other book. Also, for those of you using both books to prepare for the 200-120 CCNA exam (rather than taking the two-exam option), the end of this Introduction lists a suggested reading plan.

Book Features

The most important and somewhat obvious objective of this book is to help you pass the ICND2 exam or the CCNA exam. In fact, if the primary objective of this book were different, the book's title would be misleading! However, the methods used in this book to help you pass the exams are also designed to make you much more knowledgeable about how to do your job.

This book uses several tools to help you discover your weak topic areas, to help you improve your knowledge and skills with those topics, and to prove that you have retained your knowledge of those topics. So, this book does not try to help you pass the exams only by memorization, but by truly learning and understanding the topics. The CCNA certification is the foundation for many of the Cisco professional certifications, and it would be a disservice to you if this book did not help you truly learn the material. Therefore, this book helps you pass the CCNA exam by using the following methods:

- Helping you discover which exam topics you have not mastered

- Providing explanations and information to fill in your knowledge gaps
- Supplying exercises that enhance your ability to recall and deduce the answers to test questions
- Providing practice exercises on the topics and the testing process via test questions on the DVD

Chapter Features

To help you customize your study time using these books, the core chapters have several features that help you make the best use of your time:

- **"Do I Know This Already?" quizzes:** Each chapter begins with a quiz that helps you determine the amount of time you need to spend studying that chapter.
- **Foundation Topics:** These are the core sections of each chapter. They explain the protocols, concepts, and configuration for the topics in that chapter.
- **Exam Preparation Tasks:** At the end of the "Foundation Topics" section of each chapter, the "Exam Preparation Tasks" section lists a series of study activities that should be done at the end of the chapter. Each chapter includes the activities that make the most sense for studying the topics in that chapter. The activities include the following:
  - **Review Key Topics:** The Key Topic icon appears next to the most important items in the "Foundation Topics" section of the chapter. The Key Topics Review activity lists the key topics from the chapter and their corresponding page numbers. Although the contents of the entire chapter could be on the exam, you should definitely know the information listed in each key topic.
  - **Complete Tables and Lists from Memory:** To help you exercise your memory and memorize some lists of facts, many of the more important lists and tables from the chapter are included in a document on the DVD. This document lists only partial information, allowing you to complete the table or list.
  - **Define Key Terms:** Although the exams may be unlikely to ask a question like "Define this term," the CCNA exams require that you learn and know a lot of networking terminology. This section lists the most important terms from the chapter, asking you to write a short definition and compare your answer to the Glossary at the end of this book.
  - **Command Reference Tables:** Some book chapters cover a large amount of configuration and EXEC commands. These tables list the commands introduced in the chapter, along with an explanation. For exam preparation, use it for reference, but also read the table once when performing the Exam Preparation Tasks to make sure that you remember what all the commands do.

Part Review

The Part Review tasks help you prepare to apply all the concepts in each respective part of the book. (Each book part contains a number of related chapters.) The Part Review includes sample test questions, which require you to apply the concepts from multiple chapters in that part, uncovering what you truly understood and what you did not quite yet understand. The Part Review also uses mind map exercises that help you mentally connect concepts, configuration, and verification, so that no matter what perspective a single exam question takes, you can analyze and answer the question.

The Part Reviews list tasks, along with checklists, so you can track your progress. The following list explains the most common tasks you will see in the Part Review; note that not all Part Reviews use every type of task.

- **Review DIKTA Questions:** Although you have already seen the DIKTA questions from the chapters in a part, re-answering those questions can prove a useful way to review facts. The Part Review suggests that you repeat the DIKTA questions, but using the Pearson IT Certification Practice Test (PCPT) exam software that comes with the book, for extra practice in answering multiple choice questions on a computer.
- **Answer Part Review Questions:** The PCPT exam software includes several exam databases. One exam database holds Part Review questions, written specifically for Part Review. These questions purposefully include multiple concepts in each question, sometimes from multiple chapters, to help build the skills needed for the more challenging analysis questions on the exams.
- **Review Key Topics:** Yes, again! They are indeed the most important topics in each chapter.
- **Create Configuration Mind Maps:** Mind maps are graphical organizing tools that many people find useful when learning and processing how concepts fit together. The process of creating mind maps helps you build mental connections between concepts and configuration commands, as well as develop your recall of the individual commands. For this task, you may create the mind map on paper or using any mind mapping or graphic organizer software. (For more information about mind maps, see the section "About Mind Maps and Graphic Visualization" in the Introduction of this book.)
- **Create Verification Mind Maps:** These mind mapping exercises focus on helping you connect router and switch **show** commands to either networking concepts or to configuration commands. Simply create the mind maps on paper or using any mind mapping or graphic organizer software.
- **Repeat Chapter Review Tasks** (Optional): Browse through the Chapter Review tasks and repeat any that you think might help your review at this point.

Final Prep Tasks

Chapter 22, at the end of this book, lists a series of preparation tasks that you can best use for your final preparation before taking the exam.

Other Features

In addition to the features in each of the core chapters, this book, as a whole, has additional study resources, including the following:

- **DVD-based practice exam:** The companion DVD contains the powerful Pearson IT Certification Practice Test exam engine. You can take simulated ICND2 exams, as well as simulated CCNA exams, with the DVD and activation code included in this book. (You can take simulated ICND1 and CCNA exams with the DVD in the *Cisco CCENT/CCNA ICND1 Official Cert Guide*.)
- **CCNA ICND2 Simulator Lite:** This lite version of the best-selling CCNA Network Simulator from Pearson provides you with a means, right now, to experience the Cisco command-line interface (CLI). No need to go buy real gear or buy a full simulator to start learning the CLI. Just install it from the DVD in the back of this book.
- **eBook:** If you are interested in obtaining an eBook version of this title, we have included a special offer on a coupon card inserted in the DVD sleeve in the back of the book. This offer allows you to purchase the *Cisco CCNA Routing and Switching ICND2 200-101 Official Cert Guide Premium Edition eBook and Practice Test* at a 70 percent discount off the list price. In addition to three versions of the eBook, PDF (for reading on your computer), EPUB (for reading on your tablet, mobile device, or Nook or other eReader), and Mobi (the native Kindle version), you also receive additional practice test questions and enhanced practice test features.
- **Mentoring videos:** The DVD included with this book includes four other instructional videos, about the following topics: OSPF, EIGRP, EIGRP Metrics, plus PPP and CHAP.
- **Companion website:** The website http://www.ciscopress.com/title/1587143739 posts up-to-the-minute materials that further clarify complex exam topics. Check this site regularly for new and updated postings written by the author that provide further insight into the more troublesome topics on the exam.
- **PearsonITCertification.com:** The website http://www.pearsonitcertification.com is a great resource for all things ITcertification related. Check out the great CCNA articles, videos, blogs, and other certification preparation tools from the industry's best authors and trainers.
- **CCNA Simulator:** If you are looking for more hands-on practice, you might want to consider purchasing the CCNA Network Simulator. You can purchase a copy of this software from Pearson at http://pearsonitcertification.com/networksimulator or other retail outlets. To help you with your studies, I have created a mapping guide that maps each of the labs in the simulator to the specific sections in these CCNA cert guides. You can get this mapping guide for free on the Extras tab of the companion website.
- **Author's website and blogs:** The author maintains a website that hosts tools and links useful when studying for CCENT and CCNA. The site lists information to help you build your own lab, study pages that correspond to each chapter of this book and the ICND1 book, and links to the author's CCENT Skills blog and CCNA Skills blog. Start at http://www.certskills.com; check the tabs for study and blogs in particular.

Book Organization, Chapters, and Appendices

This book contains 21 core chapters, Chapters 1 through 21, with Chapter 22 including some suggestions for how to approach the actual exams. Each core chapter covers a subset of the topics on the ICND2 exam. The core chapters are organized into sections. The core chapters cover the following topics:

Part I: LAN Switching

- **Chapter 1, "Spanning Tree Protocol Concepts,"** discusses the concepts behind IEEE Spanning Tree Protocol (STP) and how it makes some switch interfaces block frames to prevent frames from looping continuously around a redundant switched LAN.
- **Chapter 2, "Spanning Tree Protocol Implementation,"** shows how to configure, verify, and troubleshoot STP implementation on Cisco switches.
- **Chapter 3, "Troubleshooting LAN Switching,"** reviews LAN switching topics from the ICND1 book, while moving toward a deeper understanding of those topics. In particular, this chapter examines the most common LAN switching issues and how to discover those issues when troubleshooting a network.

Part II: IP Version 4 Routing

- **Chapter 4, "Troubleshooting IPv4 Routing Part I,"** reviews IPv4 routing, and then focuses on how to use two key troubleshooting tools to find routing problems: the **ping** and **traceroute** commands.
- **Chapter 5, "Troubleshooting IPv4 Routing Part II,"** looks at the most common IPv4 problems and how to find the root causes of those problems when troubleshooting.
- **Chapter 6, "Creating Redundant First-Hop Routers,"** discusses the need for a First Hop Redundancy Protocol (FHRP), how the protocols make multiple routers act like a single default router, and the configuration and verification details of both Hot Standby Router Protocol (HSRP) and Gateway Load Balancing Protocol (GLBP).
- **Chapter 7, "Virtual Private Networks,"** discusses the need for VPN technology when sending private network data over public networks like the Internet. It also discusses basic tunneling configuration using generic routing encapsulation (GRE) tunnels on Cisco routers.

Part III: IP Version 4 Routing Protocols

- **Chapter 8, "Implementing OSPF for IPv4,"** reviews the ICND1 book's coverage of OSPF Version 2 (OSPFv2). It also takes the concepts deeper, with more discussion of the OSPF processes and database and with additional configuration options.
- **Chapter 9, "Understanding EIGRP Concepts,"** introduces the fundamental operation of the Enhanced Interior Gateway Routing Protocol (EIGRP) for IPv4 (EIGRPv4), focusing on EIGRP neighbor relationships, how it calculates metrics, and how it quickly converges to alternate feasible successor routes.
- **Chapter 10, "Implementing EIGRP for IPv4,"** takes the concepts discussed in the previous chapter and shows how to configure and verify those same features.

- **Chapter 11, "Troubleshooting IPv4 Routing Protocols,"** walks through the most common problems with IPv4 routing protocols, while alternating between OSPF examples and EIGRP examples.

Part IV: Wide-Area Networks

- **Chapter 12, "Implementing Point-to-Point WANs,"** explains the core concepts of how to build a leased-line WAN and the basics of the two common data link protocols on these links: HDLC and PPP.
- **Chapter 13, "Understanding Frame Relay Concepts,"** explains how to build a Frame Relay WAN between routers, focusing on the protocols and concepts rather than the configuration.
- **Chapter 14, "Implementing Frame Relay,"** takes the concepts discussed in Chapter 13 and shows how to configure, verify, and troubleshoot those same features.
- **Chapter 15, "Identifying Other Types of WANs,"** gives a broad description of many other types of WAN technology, including Ethernet WANs, Multiprotocol Label Switching (MPLS), and digital subscriber line (DSL).

Part V: IP Version 6

- **Chapter 16, "Troubleshooting IPv6 Routing,"** reviews IPv6 routing as discussed in the ICND1 book. It then shows some of the most common problems with IPv6 routing and discusses how to troubleshoot these problems to discover the root cause.
- **Chapter 17, "Implementing OSPF for IPv6,"** reviews the ICND1 book's coverage of OSPF Version 3 (OSPFv3). It then compares some deeper OSPFv3 concepts and configuration with these same concepts for OSPFv2, as discussed earlier in Chapter 8.
- **Chapter 18, "Implementing EIGRP for IPv6,"** takes the EIGRP concepts discussed for IPv4 in Chapter 9 and shows how those same concepts apply to EIGRP for IPv6 (EIGRPv6). It then shows how to configure and verify EIGRPv6 as well.

Part VI: Network Management

- **Chapter 19, "Managing Network Devices,"** discusses the concepts and configuration of three common network management tools: Simple Network Management Protocol (SNMP), syslog, and NetFlow.
- **Chapter 20, "Managing IOS Files,"** explains some necessary details about router internals and IOS. In particular, it discusses the boot process on a router, how a router choosing which IOS image to use, and the different locations where a router can store its IOS images.
- **Chapter 21, "Managing IOS Licensing,"** discusses Cisco's current methods of granting a particular router the right to use a particular IOS image and feature set through the use of IOS licenses.

Part VII: Final Review

- **Chapter 22, "Final Review,"** suggests a plan for final preparation once you have finished the core parts of the book, in particular explaining the many study options available in the book.

Part VIII: Appendixes (In Print)

- **Appendix A, "Numeric Reference Tables,"** lists several tables of numeric information, including a binary-to-decimal conversion table and a list of powers of 2.
- **Appendix B, "ICND2 Exam Updates,"** covers a variety of short topics that either clarify or expand on topics covered earlier in the book. This appendix is updated from time to time and posted at http://www.ciscopress.com/title/1587143739, with the most recent version available at the time of printing included here as Appendix B. (The first page of the appendix includes instructions on how to check to see if a later version of Appendix B is available online.)
- The **Glossary** contains definitions for all of the terms listed in the "Definitions of Key Terms" section at the conclusion of Chapters 1 through 21.

Appendixes (on the DVD)

The following appendixes are available in digital format on the DVD that accompanies this book:

- **Appendix C, "Answers to the 'Do I Know This Already?' Quizzes"** includes the explanations to all the questions from Chapters 1 through 21.
- **Appendix D, "Memory Tables,"** holds the key tables and lists from each chapter, with some of the content removed. You can print this appendix and, as a memory exercise, complete the tables and lists. The goal is to help you memorize facts that can be useful on the exams.
- **Appendix E, "Memory Tables Answer Key,"** contains the answer key for the exercises in Appendix D.
- **Appendix F, "Mind Map Solutions,"** shows an image of sample answers for all the part-ending mind map exercises.
- **Appendix G, "Study Planner,"** is a spreadsheet with major study milestones, where you can track your progress through your study.

Reference Information

This short section contains a few topics available for reference elsewhere in the book. You may read these when you first use the book, but you may also skip these topics and refer back to them later. In particular, make sure to note the final page of this introduction, which lists several contact details, including how to get in touch with Cisco Press.

Install the Pearson IT Certification Practice Test Engine and Questions

The DVD in the book includes the Pearson IT Certification Practice Test (PCPT) engine—software that displays and grades a set of exam-realistic multiple choice, drag-and-drop, fill-in-the-blank, and testlet questions. Using the PCPT engine, you can either study by going through the questions in study mode or take a simulated ICND2 or CCNA exam that mimics real exam conditions.

The installation process requires two major steps. The DVD in the back of this book has a recent copy of the PCPT engine. The practice exam—the database of ICND2 and CCNA exam questions—is not on the DVD. After you install the software, the PCPT software downloads the latest versions of both the software and the question databases for this book using your Internet connection.

> **Note**
>
> The cardboard DVD case in the back of this book includes both the DVD and a piece of thick paper. The paper lists the activation code for the practice exam associated with this book. *Do not lose the activation code.*

> **Note**
>
> Also on this same piece of paper, on the opposite side from the exam activation code, you will find a one-time-use coupon code that gives you 70 percent off the purchase of the *Cisco CCNA Routing and Switching ICND2 200-101 Official Cert Guide, Premium Edition eBook and Practice Test*.

Install the Software from the DVD

The software installation process is pretty routine as compared with other software installation processes. If you have already installed the Pearson IT Certification Practice Test software from another Pearson product, you do not need to reinstall the software. Instead, just launch the software on your desktop and proceed to activate the practice exam from this book by using the activation code included in the DVD sleeve. The following steps outline the installation process:

Step 1. Insert the DVD into your PC.

Step 2. The software that automatically runs is the Cisco Press software to access and use all DVD-based features, including the exam engine and the DVD-only appendixes. From the main menu, click the **Install the Exam Engine** option.

Step 3. Respond to windows prompts as with any typical software installation process.

The installation process gives you the option to activate your exam with the activation code supplied on the paper in the DVD sleeve. This process requires that you establish a Pearson website login. You need this login to activate the exam, so please do register when prompted. If you already have a Pearson website login, you do not need to register again. Just use your existing login.

Activate and Download the Practice Exam

When the exam engine is installed, you should then activate the exam associated with this book (if you did not do so during the installation process) as follows:

Step 1. Start the PCPT software from the Windows Start menu or from your desktop shortcut icon.

Step 2. To activate and download the exam associated with this book, from the My Products or Tools tab, click the **Activate** button.

Step 3. At the next screen, enter the activation key from paper inside the cardboard DVD holder in the back of the book. When it is entered, click the **Activate** button.

Step 4. The activation process downloads the practice exam. Click **Next**, and then click **Finish**.

After the activation process is completed, the My Products tab should list your new exam. If you do not see the exam, make sure you have selected the My Products tab on the menu. At this point, the software and practice exam are ready to use. Simply select the exam and click the **Open Exam** button.

To update a particular product's exams that you have already activated and downloaded, simply select the **Tools** tab and click the **Update Products** button. Updating your exams ensures that you have the latest changes and updates to the exam data.

If you want to check for updates to the PCPT software, simply select the **Tools** tab and click the **Update Application** button. This will ensure that you are running the latest version of the software engine.

Activating Other Products

The exam software installation process and the registration process have to happen only once. Then for each new product, you have to complete just a few steps. For instance, if you buy another new Cisco Press Official Cert Guide or Pearson IT Certification Cert Guide, extract the activation code from the DVD sleeve in the back of that book; you don't even need the DVD at this point. From there, all you have to do is start PCPT (if not still up and running), and perform steps 2 through 4 from the previous list.

PCPT Exam Databases with This Book

This book includes an activation code that allows you to load a set of practice questions. The questions come in different exams or exam databases. When you install the PCPT software and type in the activation code, the PCPT software downloads the latest version of all these exam databases. And with the ICND2 book alone, you get six different "exams," or six different sets of questions, as listed in Figure I-2.

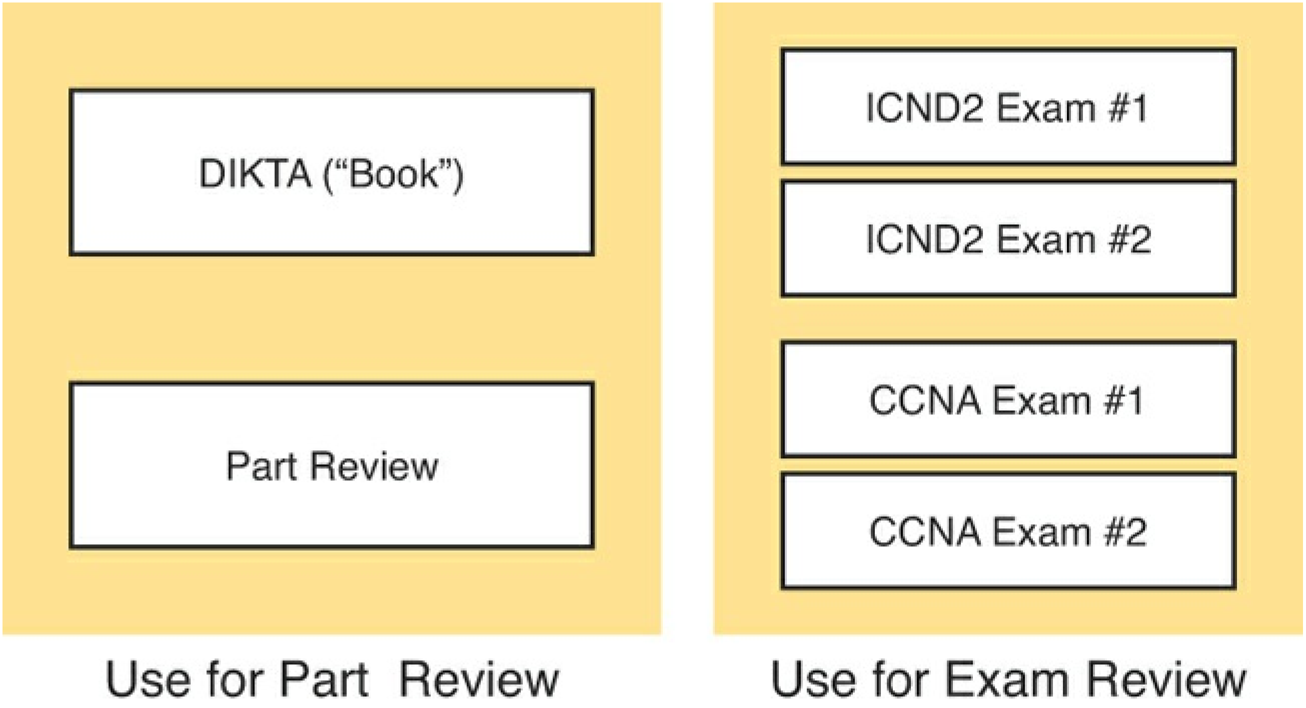


Figure I-2. PCPT Exams/Exam Databases and When to Use Them

You can choose to use any of these exam databases at any time, both in study mode and practice exam mode. However, many people find it best to save some of the exams until exam review time, after you have finished reading the entire book. Figure I-2 begins to suggest a plan, spelled out here:

- During Part Review, use PCPT to review the DIKTA questions for that part, using study mode.
  - During Part Review, use the questions built specifically for Part Review (the Part Review questions) for that part of the book, using study mode.
- Save the remaining exams to use with Chapter 22, "Final Review," using practice exam mode, as discussed in that chapter.

The two modes inside PCPT give you better options for study versus practicing a timed exam event. In study mode, you can see the answers immediately, so you can study the topics more easily. Also, you can choose a subset of the questions in an exam database; for instance, you can view questions from only the chapters in one part of the book.

Practice exam mode creates an event somewhat like the actual exam. It gives you a preset number of questions, from all chapters, with a timed event. Practice exam mode also gives you a score for that timed event.

How to View Only DIKTA Questions by Part

Each Part Review asks you to repeat the DIKTA quiz questions from the chapters in that part. You can simply scan the book pages to review these questions, but it is slightly better to review these questions from inside the PCPT software, just to get a little more practice in how to read questions from the testing software. But you can just read them in the book, as well.

To view these DIKTA (book) questions inside the PCPT software, you need to select **Book Questions**, and the chapters in this part, using the PCPT menus. To do so, follow these steps:

Step 1. Start the PCPT software.

Step 2. From the main (home) menu, select the item for this product, with a name like Cisco CCNA Routing and Switching ICND2 200-101 Official Cert Guide, and click **Open Exam**.

Step 3. The top of the next window that appears should list some exams; check the **ICND2 Book Questions** box, and uncheck the other boxes. This selects the "book" questions (that is, the DIKTA questions from the beginning of each chapter).

Step 4. On this same window, click at the bottom of the screen to deselect all objectives (chapters). Then select the box beside each chapter in the part of the book you are reviewing.

Step 5. Select any other options on the right side of the window.

Step 6. Click **Start** to start reviewing the questions.

How to View Part Review Questions by Part Only

The exam databases you get with this book include a database of questions created solely for study during the Part Review process. DIKTA questions focus more on facts, with basic application. The Part Review questions instead focus more on application and look more like real exam questions.

To view these questions, follow the same process as you did with DIKTA/book questions, but select the Part Review database rather than the book database. Specifically, follow these steps:

Step 1. Start the PCPT software.

Step 2. From the main (home) menu, select the item for this product, with a name like Cisco CCNA Routing and Switching

ICND2 200-101 Official Cert Guide, and click **Open Exam**.

Step 3. The top of the next window should list some exams; check the **Part Review Questions** box, and uncheck the other boxes. This selects the questions intended for part-ending review.

Step 4. On this same window, click at the bottom of the screen to deselect all objectives, and then select (check) the box beside the book part you want to review. This tells the PCPT software to give you Part Review questions from the selected part.

Step 5. Select any other options on the right side of the window.

Step 6. Click **Start** to start reviewing the questions.

About Mind Maps

Mind maps are a type of visual organization tool that you can use for many purposes. For instance, you can use mind maps as an alternative way to take notes.

You can also use mind maps to improve how your brain organizes concepts. Mind maps stress the connections and relationships between ideas. When you spend time thinking about an area of study, and organize your ideas into a mind map, you strengthen existing mental connections, create new connections, all into your own frame of reference.

In short, mind maps help you internalize what you learn.

Mind Map Mechanics

Each mind map begins with a blank piece of paper or blank window in an application. You then add a large central idea, with branches that move out in any direction. The branches contain smaller concepts, ideas, commands, pictures, whatever idea needs to be represented. Any concepts that can be grouped should be put near each other. As need be, you can create deeper and deeper branches, although for this book’s purposes, most mind maps will not go beyond a couple of levels.

Note

Many books have been written about mind maps, but Tony Buzan often gets credit for formalizing and popularizing mind maps. You can learn more about mind maps at his website, http://www.thinkbuzan.com.

For example, Figure I-3 shows a sample mind map that begins to output some of the IPv6 content from Part VII of the ICND1 book. The central concept of the mind map is IPv6 addressing, and the Part Review activity asks you to think of all facts you learned about IPv6 addressing, and organize them with a mind map. The mind map allows for a more visual representation of the concepts as compared with just written notes.

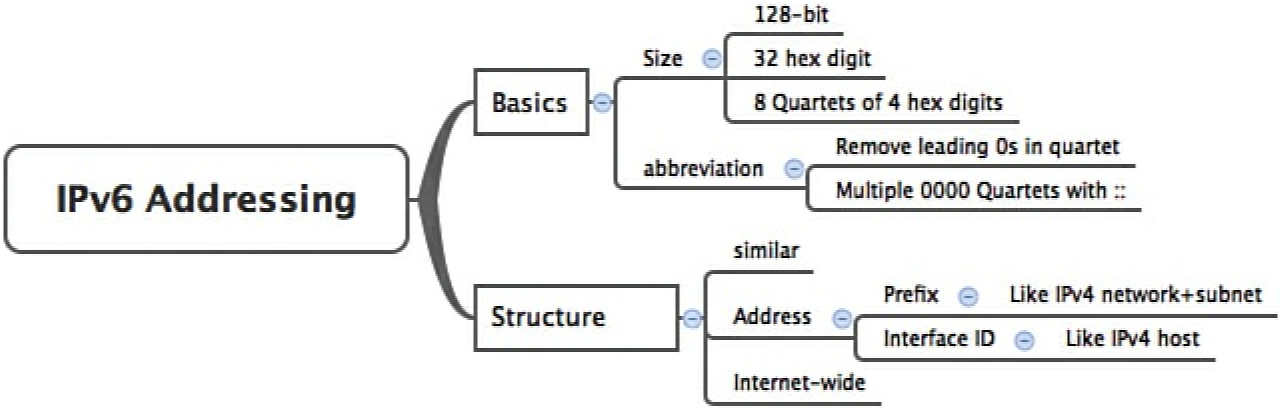


Figure I-3. Sample Mind Map

About Mind Maps Used During Part Review

This book suggests mind mapping exercises during Part Review. This short topic lists some details about the Part Review mind mapping exercises, listed in one place for reference.

Part Review uses two main types of mind mapping exercises:

> *Configuration exercises* ask you to recall the related configuration commands and group them. For instance, in a configuration exercise, related commands that happen to be interface subcommands should be grouped, but as shown as being inside interface configuration mode.
>
> *Verification exercises* ask you to think about the output of **show** commands and link the output to either the configuration commands that cause that output or the concepts that explain the meaning of some of that output.

Create these configuration mind maps on paper, using any mind mapping software, or even any drawing application. Many mind mapping apps exist as well. Regardless of how you draw them, follow these rules:

- If you have only a little time for this exercise, spend your time making your own mind map, instead of looking at suggested answers. The learning happens when thinking through the problem of making your own mind map.
- Set aside the book and all your notes, and do not look at them, when first creating these maps, and do as much as you can without looking at the book or your notes (or Google, or anything else).
- Try all the mind maps listed in a Part Review before looking at your notes.

- Finally, look at your notes to complete all the mind maps.
- Make a note of where you put your final results so that you can find them later during final exam review.

Finally, when learning to use these tools, take two other important suggestions as well. First, use as few words as possible for each node in your mind map. The point is for you to remember the idea and its connections, rather than explain the concept to someone else. Just write enough to remind yourself of the concept. Second, if the mind map process is just not working for you, discard the tool. Instead, take freeform notes on a blank piece of paper. Try to do the important part of the exercise—the thinking about what concepts go together—without letting the tool get in the way.

About Building Hands-On Skills

You need skills in using Cisco routers and switches, specifically the Cisco command-line interface (CLI). The Cisco CLI is a text-based command-and-response user interface; you type a command, and the device (a router or switch) displays messages in response. To answer sim and simlet questions on the exams, you need to know a lot of commands, and you need to be able to navigate to the right place in the CLI to use those commands.

The best way to master these commands is to use them. Sometime during your initial reading of the first part of this book, you need to decide how you personally plan to build your CLI skills. This next topic discusses your options for getting the tools you need to build CLI skills.

Overview of Lab Options

To effectively build your hands-on CLI skills, you either need real routers and switches, or at least something that acts like routers and switches. People who are new to Cisco technology often choose from a few options to get those skills.

First, you can use real Cisco routers and switches. You can buy them, new or used, or borrow them at work. You can rent them for a fee. You can even rent virtual Cisco router and switch lab pods from Cisco, in an offering called Cisco Learning Labs.

Simulators provide another option. Router and switch simulators are software products that mimic the behavior of the Cisco CLI, generally for the purpose of allowing people to learn. These products have an added advantage when learning: They usually have lab exercises as well.

Simulators come in many shapes and sizes, but the publisher sells simulators that are designed to help you with CCENT and CCNA study—plus they match this book! The Pearson CCENT Network Simulator and the Pearson CCNA Network Simulator both provide an excellent environment to practice the commands, as well as hundreds of focused labs to help you learn what you need to know for the exams. Both products have the same software code base; the CCNA product simply has labs for both ICND1 and ICND2, whereas the CCENT product has only the ICND1 labs.

This book does not tell you what option to use, but you should plan on getting some hands-on practice somehow. The important thing to know is that most people need to practice using the Cisco CLI to be ready to pass these exams.

I (Wendell) have collected some information and opinions about this decision on my website, at http://certskills.com/labgear. Those pages link to sites for Dynamips and for the Pearson simulator. Also, because the information never seemed to exist in any one place, this website includes many details about how to build a CCNA lab using used real Cisco routers and switches.

A Quick Start with Pearson Network Simulator Lite

The decision of how to get hands-on skills can be a little scary at first. The good news: You have a free and simple first step. Install the Pearson NetSim Lite that comes with this book.

This lite version of the best-selling CCNA Network Simulator from Pearson provides you with a means, right now, to experience the Cisco CLI. No need to go buy real gear or buy a full simulator to start learning the CLI. Just install it from the DVD in the back of this book.

Of course, one reason that NetSim Lite comes on the DVD is that the publisher hopes you will buy the full product. However, even if you do not use the full product, you can still learn from the labs that come with NetSim Lite while deciding about what options to pursue.

> **Note**
>
> The ICND1 and ICND2 books each contain a different version of the Sim Lite product, each with labs that match the book content. If you bought both books, make sure you install both Sim Lite products.

For More Information

If you have any comments about the book, submit them via http://www.ciscopress.com. Just go to the website, select **Contact Us**, and type your message.

Cisco might make changes that affect the CCNA certification from time to time. You should always check http://www.cisco.com/go/ccna and http://www.cisco.com/go/ccent for the latest details.

The *Cisco CCNA Routing and Switching ICND2 200-101 Official Cert Guide* helps you attain CCNA Routing and Switching certification. This is the CCNA ICND2 certification book from the only Cisco-authorized publisher. We at Cisco Press believe that this book certainly can help you achieve CCNA certification, but the real work is up to you! I trust that your time will be well spent.

Getting Started

You just got this book. You have probably already read (or quickly skimmed) the Introduction. And you are wondering, is this where I really start reading or can I skip ahead to Chapter 1, "Spanning Tree Protocol Concepts"?

Stop to read this "Getting Started" section to think about how you will study for this exam. Your study will go much better if you take time (maybe 15 minutes) to think about a few key points about how to study before starting on this journey that will take you many hours, over many weeks. That is what this "Getting Started" section will help you do.

A Brief Perspective on Cisco Certification Exams

Cisco sets the bar pretty high for passing the ICND1, ICND2, and CCNA exams. Most anyone can study and pass these exams, but it takes more than just a quick read through the book and the cash to pay for the exam.

The challenge of these exams comes from many angles. Each of these exams covers a lot of concepts and many commands specific to Cisco devices. Beyond knowledge, these Cisco exams also require deep skills. You must be able to analyze and predict what really happens in a network. You must be able to configure Cisco devices to work correctly in those networks. And you must be ready to troubleshoot problems when the network does not work correctly.

The more challenging questions on these exams work a lot like a jigsaw puzzle, but with four out of every five puzzle pieces not even in the room. To solve the puzzle, you have to mentally re-create the missing pieces. To do that, you must know each networking concept and remember how the concepts work together. You also have to match the concepts with what happens on the devices with the configuration commands that tell the devices what to do. You also have to connect the concepts and the configuration with the meaning of the output of various troubleshooting commands to analyze how the network is working and why it is not working right now.

For instance, the ICND2 exam includes many troubleshooting topics. A simple question might ask you why a router that uses Open Shortest Path Version 2 (OSPFv2) might fail to form a neighbor relationship with another neighboring router. But a more exam-realistic question would make you think about why a router is missing a route, whether the root cause is related to OSPF, and, if OSPF, whether the root cause is related to OSPF neighbors.

The questions supply some of the information, like some pieces of the jigsaw puzzle, as represented with the white pieces in Figure 1. You have to apply your knowledge of IP routing and OSPF theory to the facts to come up with some of the other pieces of the puzzle. For a given question, some pieces of the puzzle may remain a mystery, but with enough of the puzzle filled in, you should be able to answer the question. And some pieces will just remain unknown for a given question.

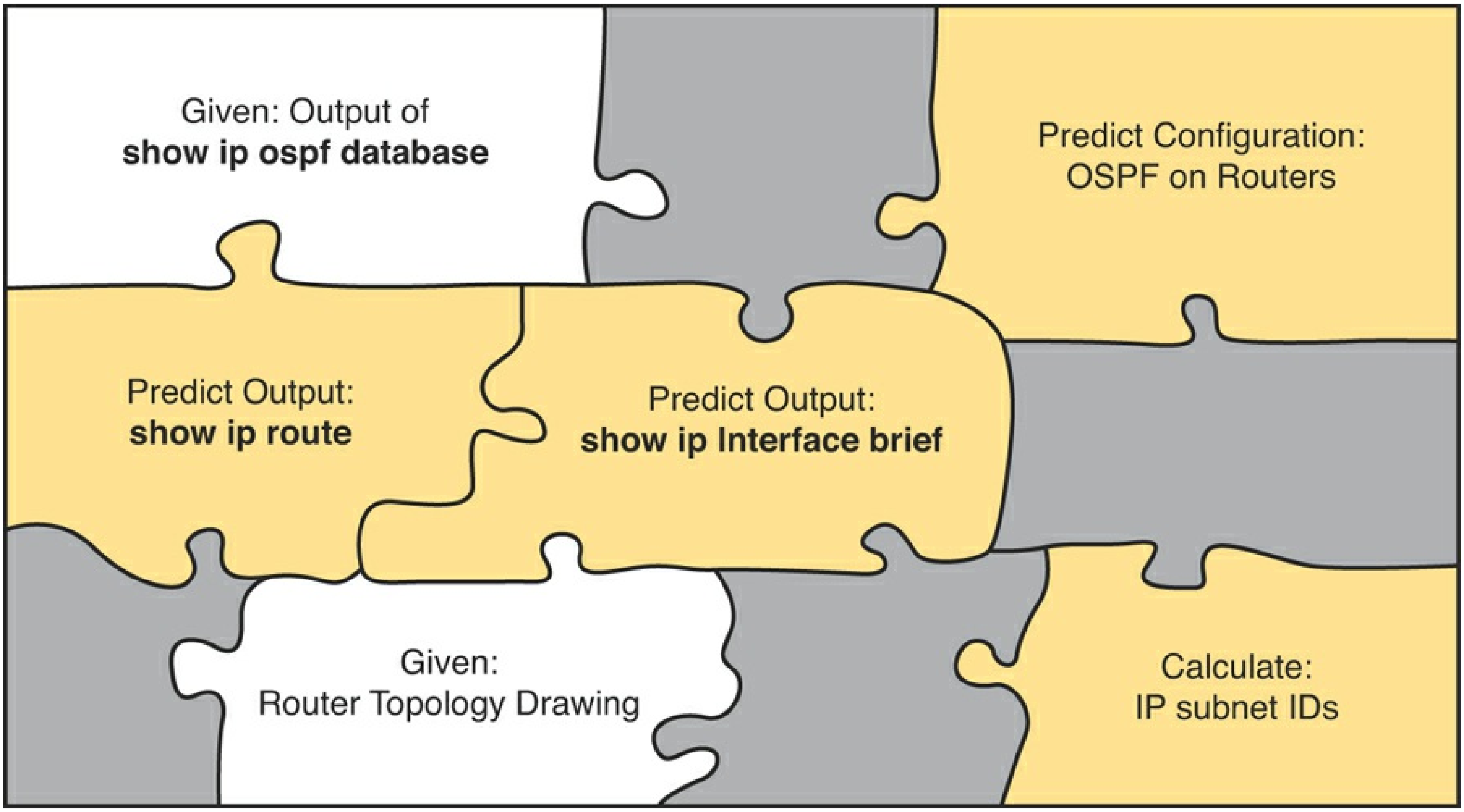


Figure 1. Filling in Puzzle Pieces with Your Analysis Skills

These skills require that you prepare by doing more than just reading and memorizing what you read. Of course, you need to read many pages in this book to learn many individual facts and how these facts relate to each other. But a big part of this book lists exercises beyond reading, exercises that help you build the skills to solve these networking puzzles.

Suggestions for How to Approach Your Study with This Book

These exams are challenging, but many people pass them every day. So, what do you need to do to be ready to pass, beyond reading and remembering all the facts? You need to develop skills. You need to mentally link each idea with other related ideas. Doing that requires additional work. To help you along the way, the next few pages give you five key perspectives about how to use this book to build those skills and make those connections, before you dive into this exciting but challenging world of learning networking on Cisco gear.

Not One Book: 21 Short Read-and-Review Sessions

First, look at your study as a series of read-and-review tasks, each on a relatively small set of related topics.

Each of the core chapters of this book (1 through 21) have around 23 pages of content on average. If you glance around any of those chapters, you will find a heading called "Foundation Topics" on about the fifth page of each chapter. From there, to the "Exam Preparation Tasks" at the end of the chapter, the chapters average about 23 pages.

So, do not approach this book as one big book. Treat the task of your first read of a chapter as a separate task. Anyone can read 23 pages. Having a tough day? Each chapter has two or three major sections, so read just one of them. Or, do some related labs, or review something you have already read. The book organizes the content into topics of a more manageable size to give you something more digestible to manage your study time throughout the book.

For Each Chapter, Do Not Neglect Practice

Next, plan to use the practice tasks at the end of each chapter.

Each chapter ends with practice and study tasks under a heading "Exam Preparation Tasks." Doing these tasks, and doing them at the end of the chapter, really does help you get ready. Do not put off using these tasks until later! The chapter-ending exam preparation tasks help you with the first phase of deepening your knowledge and skills of the key topics, remembering terms, and linking the concepts together in your brain so that you can remember how it all fits together.

The following list describes most of the activities you will find in the "Exam Preparation Tasks" sections:

- Review key topics
- Complete memory tables
- Define key terms
- Review command summary tables
- Review feature configuration checklists
- Do subnetting exercises

Approach each chapter with the same plan. You can choose to read the entire core ("Foundation Topics") section of each chapter, or you can choose to skim some chapters based on your score on the "Do I Know This Already?" (DIKTA) quiz, a pre-chapter self-assessment quiz at the beginning of most chapters. However, regardless of whether you skim or read thoroughly, do the study tasks in the "Exam Preparation Tasks" section at the end of the chapter. Figure 2 shows the overall flow.

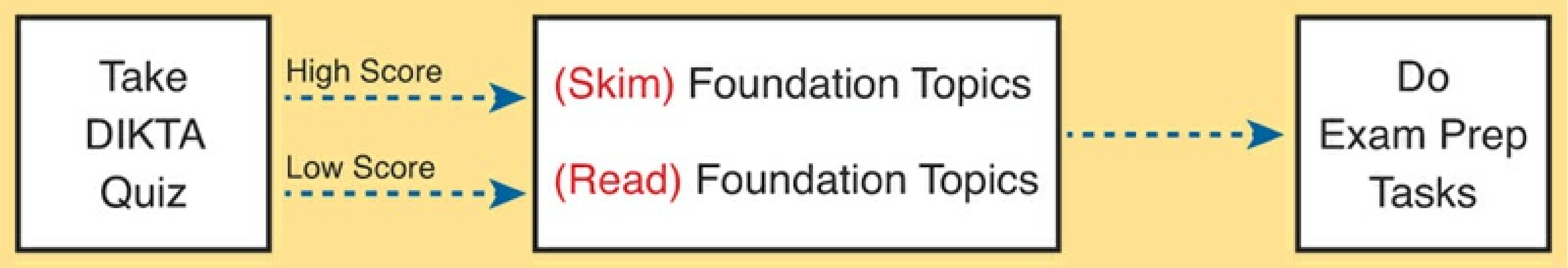


Figure 2. Suggested Approach to Each Chapter

Use Book Parts for Major Milestones

Third, view the book as having six major milestones, one for each major topic.

Beyond the more obvious organization into chapters, this book also organizes the chapters into six major topic areas called book parts. Completing each part means you have completed a major area of study. At the end of each part, take a little extra time. Do the Part Review tasks at the end of each part. Ask yourself where you are weak and where you are strong. And give yourself some reward for making it to a major milestone. Figure 3 lists the six parts in this book.

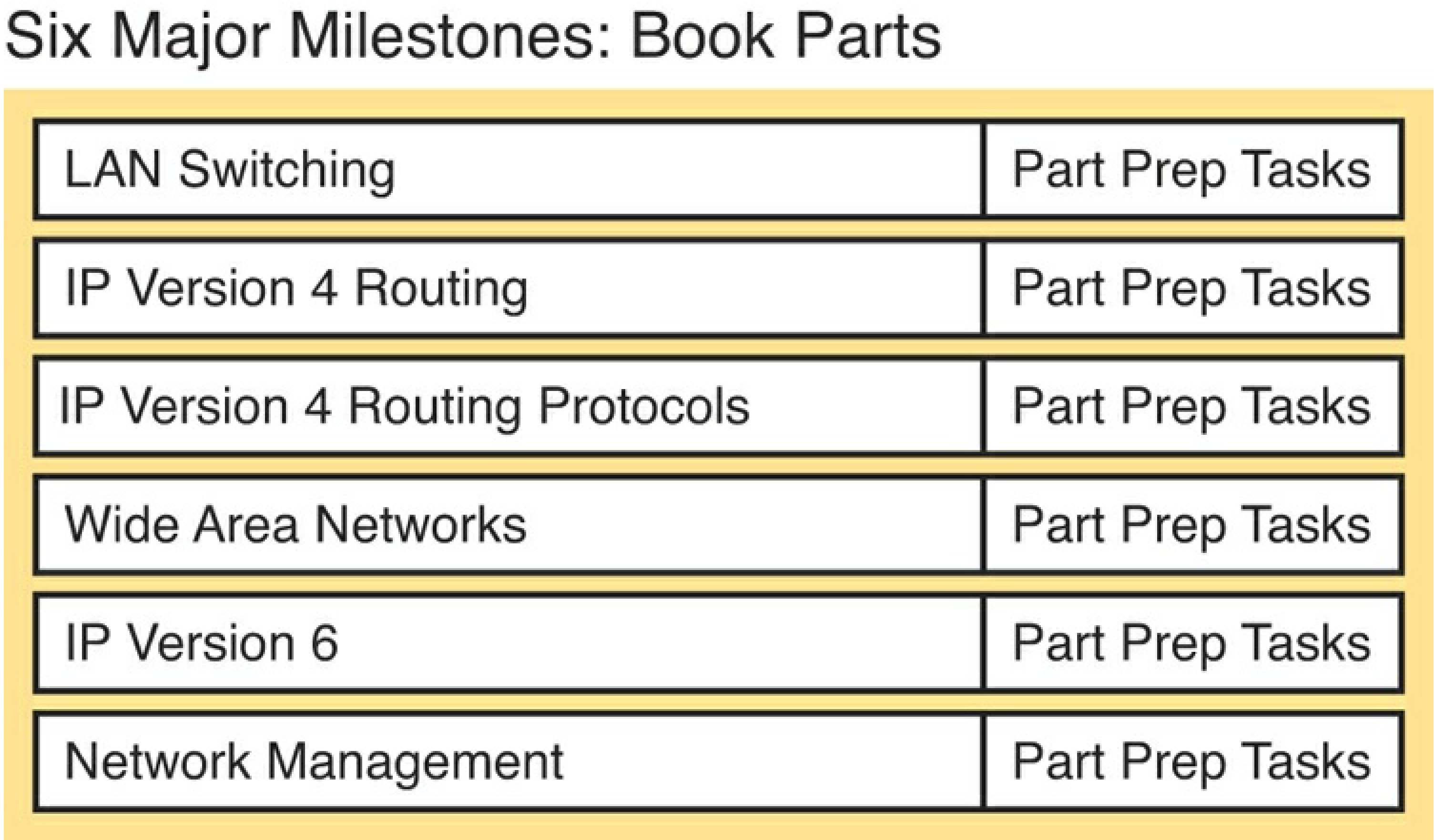


Figure 3. Parts as Major Milestones

The tasks in the Part Reviews focus on helping you apply concepts (from that book part) to new scenarios for the exam. Some tasks use sample test questions so that you can think through and analyze a problem. This process helps you refine what you know and to realize what you did not quite yet understand. Some tasks use mind map exercises that help you mentally connect the theoretical concepts with the configuration and verification commands. These Part Review activities help build these skills.

Note that the Part Review directs you to use the Pearson IT Certification Practice Test (PCPT) software to access the practice questions. Each Part Review tells you to repeat the DIKTA questions, but using the PCPT software. Each Part Review also directs you how to access a specific set of questions reserved for reviewing concepts at part review. Note that the PCPT software and exam databases with this book give you the rights to additional questions, as well; Chapter 22, "Final Review," gives some recommendations on how to best use those questions for your final exam preparation.

Also, consider setting a goal date for finishing each part of the book (and a reward, as well). Plan a break, some family time, some time out exercising, eating some good food, whatever helps you get refreshed and motivated for the next part.

Use the Final Review Chapter to Refine Skills

Fourth, do the tasks outlined in the final preparation chapter (Chapter 22) at the end of this book.

The "Final Review" chapter has two major goals. First, it helps you further develop the analysis skills you need to answer the more complicated questions on the exam. Many questions require that you connect ideas about concepts, configuration, verification, and troubleshooting. More reading on your part does not develop all these skills; this chapter's tasks give you activities to further develop these skills.

The tasks in the "Final Review" chapter also help you find your weak areas. This final element gives you repetition with high-challenge exam questions, uncovering any gaps in your knowledge. Many of the questions are purposefully designed to test your knowledge of the most common mistakes and misconceptions, helping you avoid some of the common pitfalls people experience with the actual exam.

Set Goals and Track Your Progress

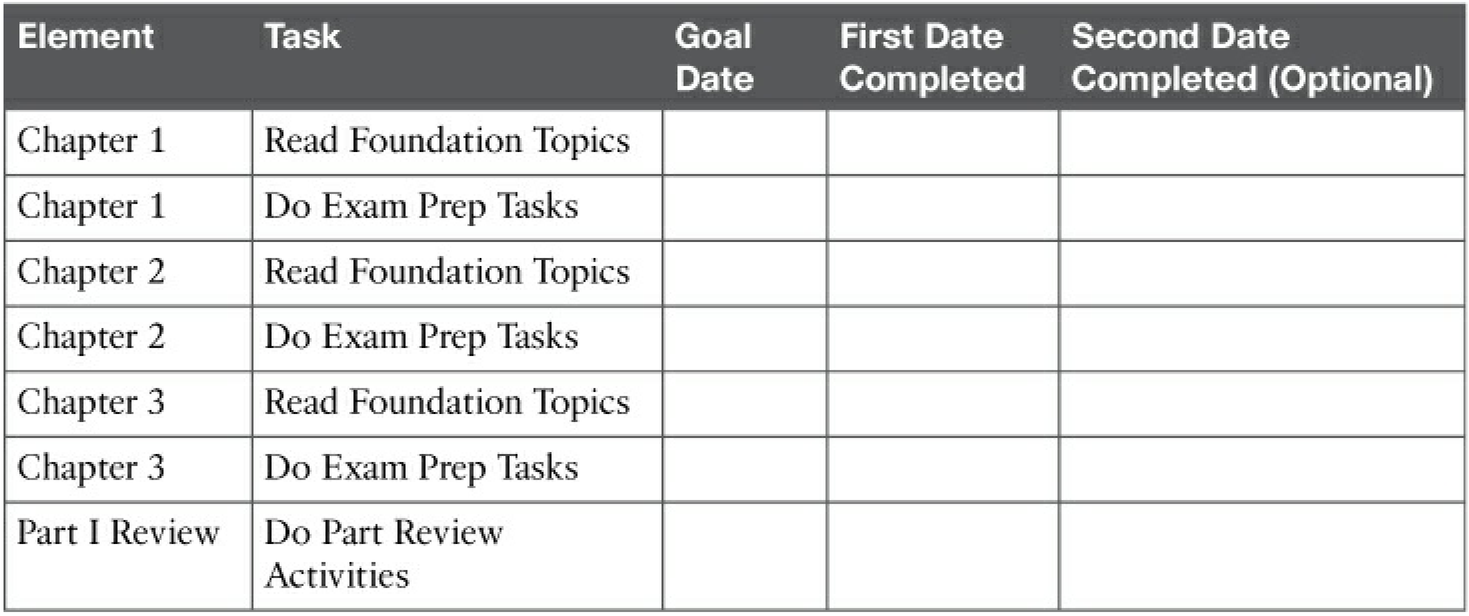
Finally, before you start reading the book and doing the rest of these study tasks, take the time to make a plan, set some goals, and be ready to track your progress.

While making lists of tasks may or may not appeal to you, depending on your personality, goal setting can help everyone studying for these exams. And to do the goal setting, you need to know what tasks you plan to do.

As for the list of tasks to do when studying, you do not have to use a detailed task list. (You could list every single task in every chapter-ending "Exam Preparation Tasks" section, every task in the Part Reviews, and every task in the "Final Preparation" chapter.) However, listing the major tasks can be enough.

You should track at least two tasks for each typical chapter: reading the "Foundation Topics" section and doing the "Exam Preparation Tasks" at the end of the chapter. And of course, do not forget to list tasks for Part Reviews and Final Review. Table 1 shows a sample for Part I of this book.

Table 1. Sample Excerpt from a Planning Table



Element	Task	Goal Date	First Date Completed	Second Date Completed (Optional)
Chapter 1	Read Foundation Topics			
Chapter 1	Do Exam Prep Tasks			
Chapter 2	Read Foundation Topics			
Chapter 2	Do Exam Prep Tasks			
Chapter 3	Read Foundation Topics			
Chapter 3	Do Exam Prep Tasks			
Part I Review	Do Part Review Activities			

Note

Appendix G, "Study Planner," on the DVD that comes with this book, contains a complete planning checklist like Table 1 for the tasks in this book. This spreadsheet allows you to update and save the file to note your goal dates and the tasks you have completed.

Use your goal dates as a way to manage your study, and not as a way to get discouraged if you miss a date. Pick reasonable dates that you can meet. When setting your goals, think about how fast you read and the length of each chapter's "Foundation Topics" section, as listed in the table of contents. Then, when you finish a task sooner than planned, move up the next few goal dates.

If you miss a few dates, do *not* start skipping the tasks listed at the ends of the chapters! Instead, think about what is impacting your schedule—real life, commitment, and so on—and either adjust your goals or work a little harder on your study.

Two Options When Studying for the 200-120 CCNA Exam

To get a CCNA Routing and Switching certification, you choose either a one-exam or two-exam path.

When using the two-exam path, use each book separately, and take the matching Cisco exam. In other words, use the *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*, and then pass the 100-101 ICND1 exam, and then do the same with the *Cisco CCNA Routing and Switching ICND2 200-101 Official Cert Guide* and the 200-101 ICND2 exam.

The one-exam path gives you a couple of study options. The 200-120 CCNA exam covers the topics in the combined ICND1 and ICND2 books. The only question is when to read each part of the two books. You have two reasonable options when going with the one-exam option:

- Complete all the ICND1 book, then move on to the ICND2 book
- Move back and forth between the ICND1 and ICND2 books, by part, based on topics

The first option is pretty obvious, but the second one is less obvious. So, Figure 4 shows a study plan when you are using the one-exam option and want to move back and forth between the two books. Why move back and forth? To read about similar topics all at once, as shown in Figure 4.

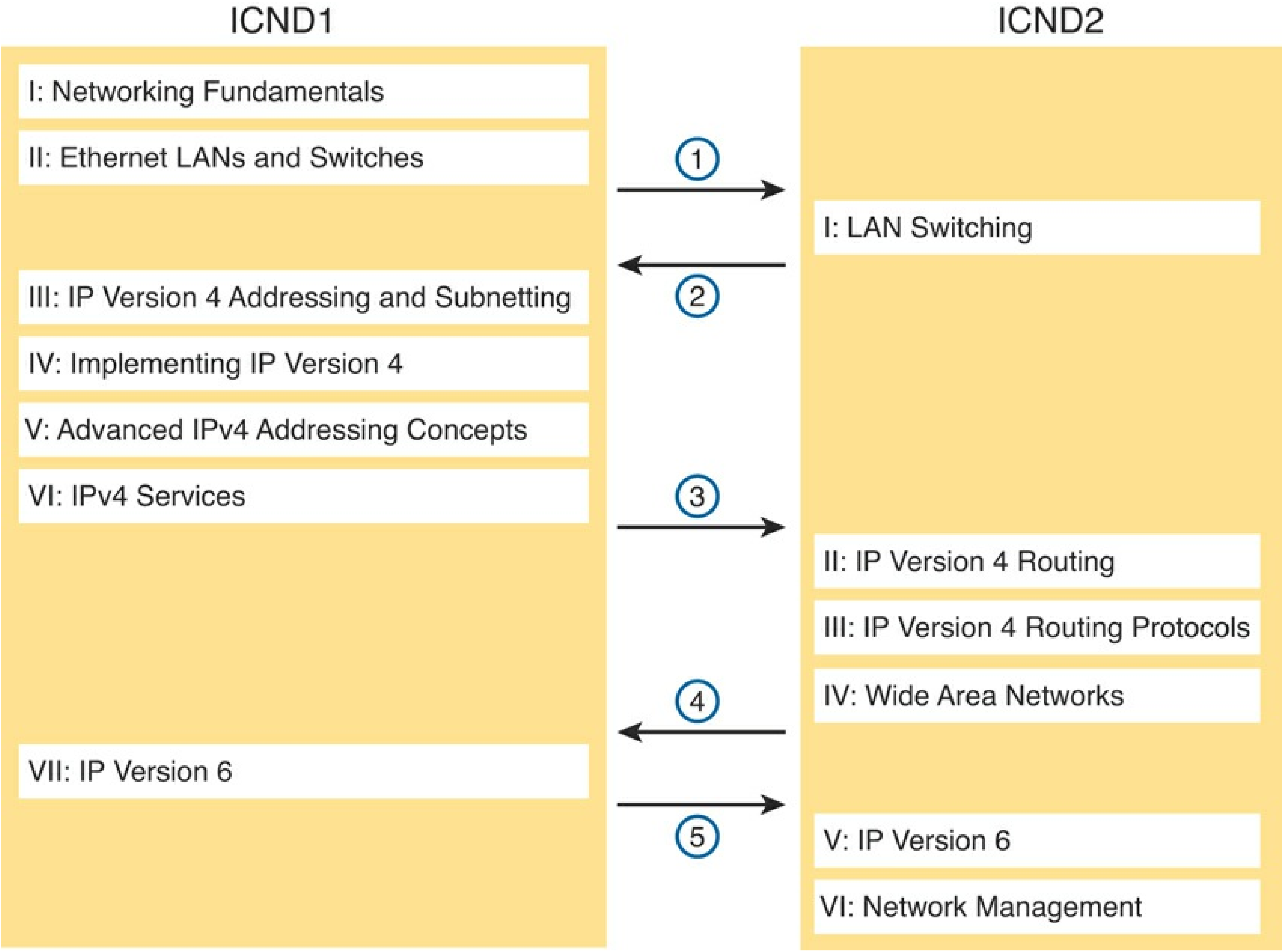

ICND1
ICND2
I: Networking Fundamentals
II: Ethernet LANs and Switches
III: IP Version 4 Addressing and Subnetting
IV: Implementing IP Version 4
V: Advanced IPv4 Addressing Concepts
VI: IPv4 Services
VII: IP Version 6
①
②
③
④
⑤
I: LAN Switching
II: IP Version 4 Routing
III: IP Version 4 Routing Protocols
IV: Wide Area Networks
V: IP Version 6
VI: Network Management

Figure 4. Alternate Reading Plan for CCNA: Moving Between Books by Part

Note that you should wait to use the "Final Review" chapter of either book until you complete both books. However, do the Part Review activities at the end of each part.

Other Small Tasks Before Getting Started

You need to do a few overhead tasks to install software, find some PDFs, and so on. You can do these tasks now or do them in your spare moments when you need a study break during the first few chapters of the book. But do these early. That way, if you do stumble upon an installation problem, you have time to work through it before you need a particular tool.

Register (for free) at the Cisco Learning Network (CLN, http://learningnetwork.cisco.com) and join the CCENT and CCNA study groups. These mailing lists allow you to lurk and participate in discussions about topics related to CCENT (ICND1) and CCNA (ICND1 + ICND2). Register, join the groups, and set up an email filter to redirect the messages to a separate folder. Even if you do not spend time reading all the posts yet, later, when you have time to read, you can browse through the posts to find interesting topics (or just search the posts from the CLN website).

Find and print a copy of Appendix D, "Memory Tables." Many of the "Chapter Review" sections use this tool, in which you take the incomplete tables from the appendix and complete the table to help you remember some key facts.

If you bought an ebook version of this book, find and download the media files (videos and Sim Lite software) per the instructions supplied on the last page of the ebook file under a "Where Are the Companion Files" heading.

Install the PCPT exam software and activate the exams. For more details on how to load the software, refer back to the Introduction, in the section "Install the Pearson Certification Practice Test Engine and Questions."

Finally, install the Sim Lite software (unless you bought the full simulator product already). The Sim Lite that comes with this book contains a subset of the lab exercises in the full Pearson Network Simulator product.

Getting Started: Now

Now dive in to your first of many short, manageable tasks: reading the relatively short introductory Chapter 1. Enjoy!

Part I: LAN Switching

Chapter 1: Spanning Tree Protocol Concepts

Chapter 2: Spanning Tree Protocol Implementation

Chapter 3: Troubleshooting LAN Switching

Part I Review

Part I of the book focuses on Ethernet LAN topics. In practice, many fundamental Ethernet LAN topics are pre-requisites for this book. The CCENT certification, and the matching *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*, contains a fairly deep discussion about Ethernet LANs; roughly 20% of the *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide* is devoted to LAN topics. Part I of this ICND2 book picks up the Ethernet story assuming you already know Ethernet LAN basics.

Part I of this book completes the Ethernet LAN topics for the CCNA exam by adding to what is included in CCENT. In particular, this part discusses the concepts, configuration, and verification of the Spanning Tree Protocol (STP, Chapters 1 and 2). In addition, this part reviews most of the Ethernet LAN topics from CCENT—first to help you remember some of the details, but also to prepare everyone for learning about how to troubleshoot Ethernet LANs (Chapter 3).

Chapter 1. Spanning Tree Protocol Concepts

This chapter covers the following exam topics:

LAN Switching Technologies

Identify advanced switching technologies

- RSTP
- PVSTP
- EtherChannels

Configure and verify PVSTP operation

- Describe root bridge election

Spanning Tree Protocol (STP) allows Ethernet LANs to have the added benefits of installing redundant links in a LAN, while overcoming the known problems that occur when adding those extra links. Using redundant links in a LAN design allows the LAN to keep working even when some links fail or even when some entire switches fail. Proper LAN design should add enough redundancy so that no single point of failure crashes the LAN; STP allows the design to use redundancy without causing some other problems.

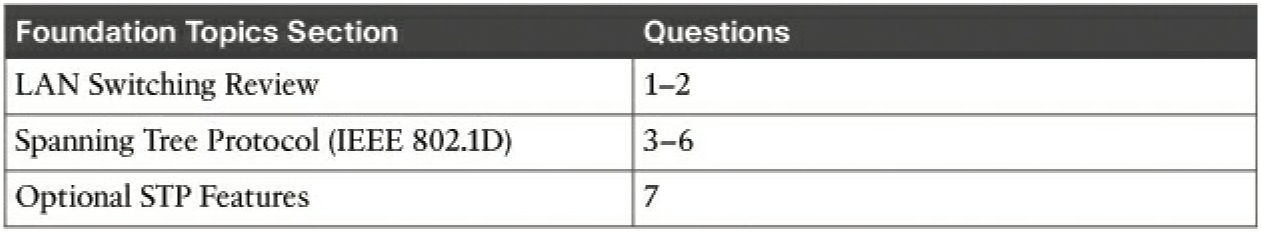
This chapter discusses the concepts behind STP. In particular, it discusses why LANs need STP, what STP does to solve certain problems in LANs with redundant links, and how STP does its work. This chapter breaks the STP discussions into two major sections: the first about the core functions of STP, and the second about some optional STP features.

However, before moving on to STP, the first section of this chapter reviews LAN switching topics. For some of you reading this book, you easily remember about LAN switching, forwarding frames, MAC address tables, and everything to do with Ethernet LANs. Maybe you recently got your CCENT certification by passing the ICND1 exam, or maybe you just finished reading the ICND1 100-101 Official Cert Guide. However, some of you might not remember these details. So, the first section of the chapter provides a brief review of some important Ethernet topics from ICND1, so that when you read about STP, the Ethernet details will be fresh in your mind.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 1-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
LAN Switching Review	1–2
Spanning Tree Protocol (IEEE 802.1D)	3–6
Optional STP Features	7

1. An Ethernet frame arrives at switch SW1, entering on port F0/1. F0/1 does not trunk. SW1 forwards the frame out F0/2. Which of the following statements is true about the logic SW1 uses when forwarding the frame?

   a. Forward based on MAC table entries for the F0/1's access VLAN

   b. Forward based on MAC table entries for the F0/2's access VLAN

   c. Forward based on MAC table entries for the F0/1's native VLAN

   d. Forward based on MAC table entries in all VLANs

2. Consider the following command output:

Click here to view code image

```
SW1# show interfaces f0/11 status

Port Name Status Vlan Duplex Speed Type
Fa0/11 connected 3 a-full 100 10/100BaseTX
```

A frame arrives on this same switch's port F0/1, an access port in VLAN 3. The frame is destined to MAC address FFFF.FFFF.FFFF. Which of the following statements is true, based on the information about F0/11 in the **show** command output, about whether SW1 will forward the frame out port F0/11?

a. The output confirms that SW1 will definitely forward the frame out F0/11.

b. The output confirms that SW1 will definitely not forward the frame out F0/11.

c. The output confirms that it is possible for SW1 to forward the frame out F0/11, but not definitely.

3. Which of the following IEEE 802.1D port states are stable states used when STP has completed convergence? (Choose two answers.)

   a. Blocking

   b. Forwarding

   c. Listening

   d. Learning

   e. Discarding

4. Which of the following are transitory IEEE 802.1D port states used only during the process of STP convergence? (Choose two answers.)

   a. Blocking

   b. Forwarding

   c. Listening

   d. Learning

   e. Discarding

5. Which of the following bridge IDs win election as root, assuming that the switches with these bridge IDs are in the same network?

   a. 32769:0200.1111.1111

   b. 32769:0200.2222.2222

   c. 4097:0200.1111.1111

   d. 4097:0200.2222.2222

   e. 40961:0200.1111.1111

6. Which of the following facts determines how often a nonroot bridge or switch sends an 802.1D STP hello BPDU message?

   a. The hello timer as configured on that switch.

   b. The hello timer as configured on the root switch.

   c. It is always every 2 seconds.

   d. The switch reacts to BPDUs received from the root switch by sending another BPDU 2 seconds after receiving the root BPDU.

7. What STP feature causes an interface to be placed in the forwarding state as soon as the interface is physically active?

   a. STP

   b. EtherChannel

   c. Root Guard

   d. PortFast

Answers to the "Do I Know This Already?" quiz:

1 A **2** C **3** A and B **4** C and D **5** C **6** B **7** D

Foundation Topics

LAN Switching Review

> **Note**
>
> This section reviews Ethernet LAN switching topics from the ICND1 exam and CCENT certification. Feel free to skim or skip forward to the next major heading, "Spanning Tree Protocol," if you remember Ethernet LAN topics well.

Modern LANs create a network of both wired and wireless connections to a variety of devices. Those connections give any device the fundamental means to send and receive data to and from other devices in a network. Combined with WAN connections and the Internet, these LAN-connected devices can communicate with other devices in other parts of an Enterprise network and across the world.

The wired parts of modern LANs use Ethernet standards and LAN switches. The Ethernet standards define the cabling details, as well as the data link layer rules, including framing and addresses. Physically, an Ethernet LAN may be small or large, but it has three basic components:

- Devices with an Ethernet network interface card (NIC)
- Ethernet LAN switches
- Cables that connect devices (NICs to switch ports, switch ports to each other, and so on)

Figure 1-1 shows an example with six PCs connected to a single LAN switch.

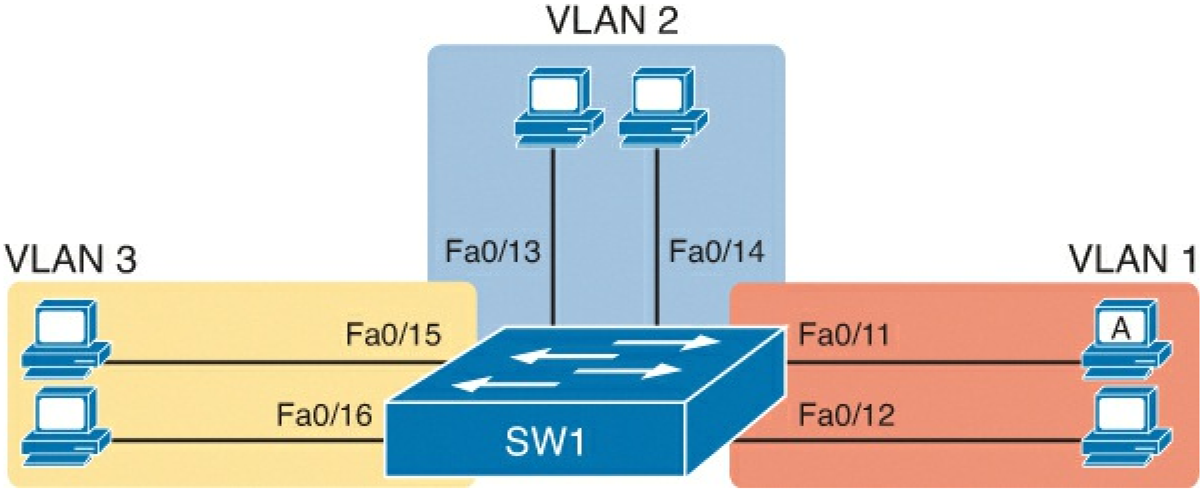


Figure 1-1. Small Ethernet LAN with VLANs

LAN Switch Forwarding Logic

STP limits where a switch chooses to forward frames, for the purpose of preventing problems with loops. These problems happen because, in some cases, the core LAN switch logic would literally forward a frame around the LAN forever without some external method like STP to prevent it. So, to understand STP, you need a good recall of the core logic of a LAN switch, particularly the switch forwarding logic. Then you can understand why frames would loop without STP, and then how STP prevents the loop.

The following list details all the steps in how a LAN switch forwards a frame, while ignoring the role of STP.

Key Topic

Step 1. Determine the VLAN in which the frame should be forwarded, as follows:

  A. If the frame arrives on an access interface, use the interface's access VLAN.

  B. If the frame arrives on a trunk interface, use the VLAN listed in the frame's trunking header.

Step 2. Add the source MAC address to the MAC address table, with incoming interface and VLAN ID.

Step 3. Look for the destination MAC address of the frame in the MAC address table, but only for entries in the VLAN identified at Step 1. Follow one of the next steps depending on whether the destination MAC is found:

  A. Found: Forward the frame out the only interface listed in the matched address table entry.

  B. Not found: Flood the frame out all other access ports in that same VLAN and out all trunk ports that list this VLAN as fully supported (active, in the allowed list, not pruned, STP forwarding).

For example, in Figure 1-1, consider a frame sent by PC A. The figure implies that switch port F0/11 is in VLAN 1, so at Step 1 in the process, the switch determines the frame is in VLAN 1. The switch would not forward the frame out the ports in VLAN 2 (F0/13 and F0/14) or VLAN 3 (F0/15 and F0/16). Then, the switch would look for the destination MAC address in the MAC address table, but only for entries in VLAN 1.

Later, this chapter discusses how STP adds to this logic, limiting the interfaces that a switch uses when both receiving frames and forwarding frames, thereby preventing loops.

Switch Verification

LAN switch logic really does reduce to a pretty short description, and it should, because switches need to forward potentially millions of frames per second (fps). Receive the frame, determine the VLAN, match the destination MAC to the MAC table, choose the outgoing interfaces, and forward the frame. However, making sense of the **show** commands can be a little more challenging, particularly if you do not get to use them in real networks every day. This section reviews a couple of key **show** commands that will prove useful when thinking about STP.

Viewing the MAC Address Table

The first example lists the MAC address table on two switches, SW1 and SW2, as shown in Figure 1-2. The figure shows the concept behind these MAC address tables, with the two PCs and one router being in VLAN 10. Example 1-1 that follows shows the output of the **show mac address-table dynamic** command, which lists all dynamically learned MAC table entries on a switch, for all VLANs.

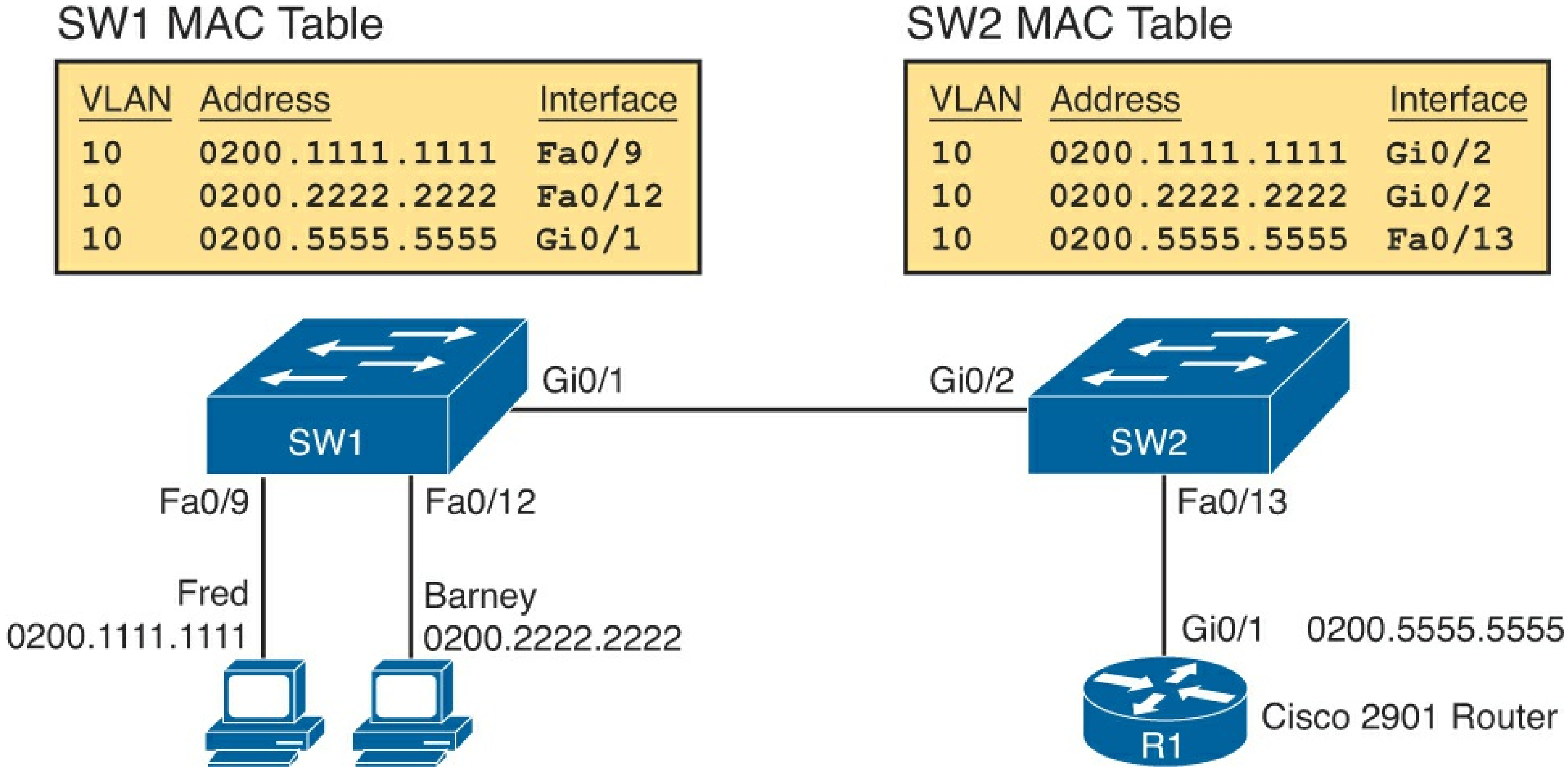

SW1 MAC Table
VLAN Address Interface
10 0200.1111.1111 Fa0/9
10 0200.2222.2222 Fa0/12
10 0200.5555.5555 Gi0/1
SW2 MAC Table
VLAN Address Interface
10 0200.1111.1111 Gi0/2
10 0200.2222.2222 Gi0/2
10 0200.5555.5555 Fa0/13
SW1
Gi0/1
Gi0/2
SW2
Fa0/9
Fa0/12
Fa0/13
Fred
0200.1111.1111
Barney
0200.2222.2222
Gi0/1
0200.5555.5555
R1
Cisco 2901 Router

Figure 1-2. Sample LAN with Pseudo MAC Address Tables

Example 1-1. Examining SW1 and SW2 Dynamic MAC Address Table Entries

Click here to view code image

```
SW1# show mac address-table dynamic
Mac Address Table
-------------------------------------------

Vlan Mac Address Type Ports
---- ----------- -------- -----
10 0200.1111.1111 DYNAMIC Fa0/9
10 0200.2222.2222 DYNAMIC Fa0/12
10 0200.5555.5555 DYNAMIC Gi0/1
```

```
SW2# show mac address-table dynamic
Mac Address Table
-------------------------------------------

Vlan Mac Address Type Ports
---- ----------- -------- -----
10 0200.1111.1111 DYNAMIC Gi0/2
10 0200.2222.2222 DYNAMIC Gi0/2
10 0200.5555.5555 DYNAMIC Fa0/13
```

Note that each command, on each switch, basically repeats the same MAC table information shown in Figure 1-2. Both have learned all three MAC addresses, so each of the three devices must have sent frames that reached both switches. However, note that each switch has different forwarding (port) information. For instance, Fred's MAC address of 0200.1111.1111 is listed off SW1's Fa0/9 port, but SW2's MAC address table lists SW2's Gi0/2 port. So, the forwarding details in the table tell the local switch out which of its local ports to forward the frame.

STP does not leave any specific tracks or notes in the output of this command. However, STP will impact the set of ports on which a switch can learn MAC addresses, so STP indirectly changes what output shows up in the output of the **show mac address-table** command. As will be discussed later in the chapter, STP will cause a port to block, meaning that the switch ignores frames entering the interface. As a result, the switch will not learn MAC addresses from those frames, which affects the entries listed in the **show mac address-table** command.

Determining the VLAN of a Frame

The forwarding process of a Layer 2 switch forwards the frame in the context of a single VLAN. That is, the frame enters a switch, and the switch must determine the VLAN in which the frame arrived. Then, the Layer 2 switch forwards the frame out ports in that same VLAN only, or out trunk ports that support that VLAN.

Cisco switch ports operate either as an access port or a trunk port, and the type of port determines how the switch determines the incoming frame's VLAN. As an access port, the switch associates a single VLAN with the interface. Frames that arrive on an access port are assumed to be part of the access VLAN, which you configure using the **switchport access vlan** *vlan-id* interface subcommand. For trunk ports, the frame arrives with a VLAN tag as part of the trunking header; that tag identifies the VLAN ID.

Example 1-2 lists a couple of **show** commands that list switch interfaces and related VLAN information. The **show interfaces status** command lists all switch interfaces and their current status. It also lists either the interface's VLAN, if operating as an access port, or it lists the fact that the port is working as a trunk.

Example 1-2. Displaying Interfaces and VLANs

Click here to view code image

```
SW1# show interfaces status

Port Name Status Vlan Duplex Speed Type
Fa0/1 notconnect 1 auto auto 10/100BaseTX
Fa0/2 notconnect 1 auto auto 10/100BaseTX
Fa0/3 notconnect 1 auto auto 10/100BaseTX
Fa0/4 connected 1 a-full a-100 10/100BaseTX
Fa0/5 connected 1 a-full a-100 10/100BaseTX
Fa0/6 notconnect 1 auto auto 10/100BaseTX
Fa0/7 notconnect 1 auto auto 10/100BaseTX
Fa0/8 notconnect 1 auto auto 10/100BaseTX
Fa0/9 connected 10 auto auto 10/100BaseTX
Fa0/10 notconnect 1 auto auto 10/100BaseTX
Fa0/11 connected 1 a-full 10 10/100BaseTX
Fa0/12 connected 10 half 100 10/100BaseTX
Fa0/13 connected 1 a-full a-100 10/100BaseTX
Fa0/14 disabled 1 auto auto 10/100BaseTX
Fa0/15 connected 3 auto auto 10/100BaseTX
Fa0/16 connected 3 a-full 100 10/100BaseTX
Fa0/17 connected 1 a-full a-100 10/100BaseTX
Fa0/18 notconnect 1 auto auto 10/100BaseTX
Fa0/19 notconnect 1 auto auto 10/100BaseTX
Fa0/20 notconnect 1 auto auto 10/100BaseTX
Fa0/21 notconnect 1 auto auto 10/100BaseTX
Fa0/22 notconnect 1 auto auto 10/100BaseTX
Fa0/23 notconnect 1 auto auto 10/100BaseTX
Fa0/24 notconnect 1 auto auto 10/100BaseTX
Gi0/1 connected trunk full 1000 10/100/1000BaseTX
Gi0/2 notconnect 1 auto auto 10/100/1000BaseTX

SW1# show vlan brief

VLAN Name Status Ports
---- -------------------------------- --------- -------------------------------
1 default active Fa0/1, Fa0/2, Fa0/3, Fa0/4
Fa0/5, Fa0/6, Fa0/7, Fa0/8
Fa0/9, Fa0/10, Fa0/11, Fa0/12
Fa0/17, Fa0/18, Fa0/19, Fa0/20
Fa0/21, Fa0/22, Fa0/23, Fa0/24
Gi0/2
3 VLAN0003 active Fa0/15, Fa0/16
10 WO-example active Fa0/9, Fa0/12
1002 fddi-default act/unsup
1003 token-ring-default act/unsup
1004 fddinet-default act/unsup
1005 trnet-default act/unsup
```

The bottom of the example lists output from the **show vlan** command, which lists all VLANs, with a matching list of all access ports assigned to each VLAN. (Note that these commands match Figure 1-1, shown earlier.)

Taking a moment to think about STP's job again. STP has no impact on either of the commands in Example 1-2, either. For instance, with **show interfaces status**, STP does not change the VLAN assignments, change the trunking status, or change an interface's status from "connected" to something else. STP requires the use of commands that begin with **show spanning-tree**, with that information applied to all the usual information about interfaces, whether they are access or trunk links, and the VLANs they support.

Verifying Trunks

The final review topic lists the output of the one LAN switching command from the earlier discussions that does happen to show some direct evidence of STP: the **show interfaces trunk** command.

A Cisco switch interface will operate in VLAN trunking mode if configured correctly on both ends of the trunk. That trunk can support all VLANs known to the local switch. However, the trunk can choose to not forward frames for some VLANs, due to various switch features; one of those features is STP.

The **show interfaces trunk** command identifies a couple of important ideas. First, it lists only currently operational trunks; it does not list trunks that might negotiate trunking at some future time. It also lists the VLANs for which the switch currently forwards frames, in the last line of output for each port. Example 1-3 shows an example.

Example 1-3. show interfaces trunk **with Focus on the Last List of VLANs**

Click here to view code image

```
SW1# show interfaces trunk

Port Mode Encapsulation Status Native vlan
Gi0/1 desirable 802.1q trunking 1

Port Vlans allowed on trunk
Gi0/1 1-4094

Port Vlans allowed and active in management domain
Gi0/1 1, 3, 10

Port Vlans in spanning tree forwarding state and not pruned
Gi0/1 1, 3, 10
```

The output of this command lists four groups of messages. The first summarizes the list of operational trunks and their settings. The next three list the VLANs supported on each trunk, in progressively more restrictive lists. Any VLANs listed in the final list (highlighted) can be forwarded and received by that port. In this case, SW1's port Gi0/1 will forward frames for VLANs 1, 3, and 10, but for no others.

This command is important to STP because it lists some information directly impacted by STP. STP uses port states called forwarding and blocking, per VLAN. If STP blocks a port in a particular VLAN, that VLAN will not be in the final list at the bottom of the **show interfaces trunk** command. (Chapter 2, "Spanning Tree Protocol Implementation," which discusses STP configuration and verification, shows examples of STP blocking and the effects on this command.)

Spanning Tree Protocol (IEEE 802.1D)

Without Spanning Tree Protocol (STP), a LAN with redundant links would cause Ethernet frames to loop for an indefinite period of time. With STP enabled, some switches block ports so that these ports do not forward frames. STP intelligently chooses which ports block, with two goals in mind:

- All devices in a VLAN can send frames to all other devices. In other words, STP does not block too many ports, cutting off some parts of the LAN from other parts.
- Frames have a short life and do not loop around the network indefinitely.

STP strikes a balance, allowing frames to be delivered to each device, without causing the problems that occur when frames loop through the network over and over again.

STP prevents looping frames by adding an additional check on each interface before a switch uses it to send or receive user traffic. That check: If the port is in STP forwarding state in that VLAN, use it as normal; if it is in STP blocking state, however, block all user traffic and do not send or receive user traffic on that interface in that VLAN.

Note that these STP states do not change the other information you already know about switch interfaces. The interface's state of connected/notconnect does not change. The interface's operational state as either an access or trunk port does not change. STP adds this additional STP state, with the blocking state basically disabling the interface.

In many ways, those last two paragraphs sum up what STP does. However, the details of how STP does its work can take a fair amount of study and practice. This second major section of the chapter begins by explaining the need for STP and the basic ideas of what STP does to solve the problem of looping frames. The majority of this section then looks at how STP goes about choosing which switch ports to block to accomplish STP's goals.

The Need for Spanning Tree

STP prevents three common problems in Ethernet LANs that would occur if the LAN were to have redundant links and STP were not used. All three problems are actually side effects of the fact that without STP, some Ethernet frames would loop around the network for a long time (hours, days, literally forever if the LAN devices and links never failed).

Just one frame that loops around a network causes what is called a broadcast storm. Broadcast storms happen when broadcast frames, multicast frames, or unknown-destination unicast frames loop around a LAN indefinitely. Broadcast storms can saturate all the links with copies of that one single frame, crowding out good frames, as well as significantly impacting end-user PC performance by making the PCs process too many broadcast frames.

To help you understand how this occurs, Figure 1-3 shows a sample network in which Bob sends a broadcast frame. The dashed lines show how the switches forward the frame when STP does not exist.

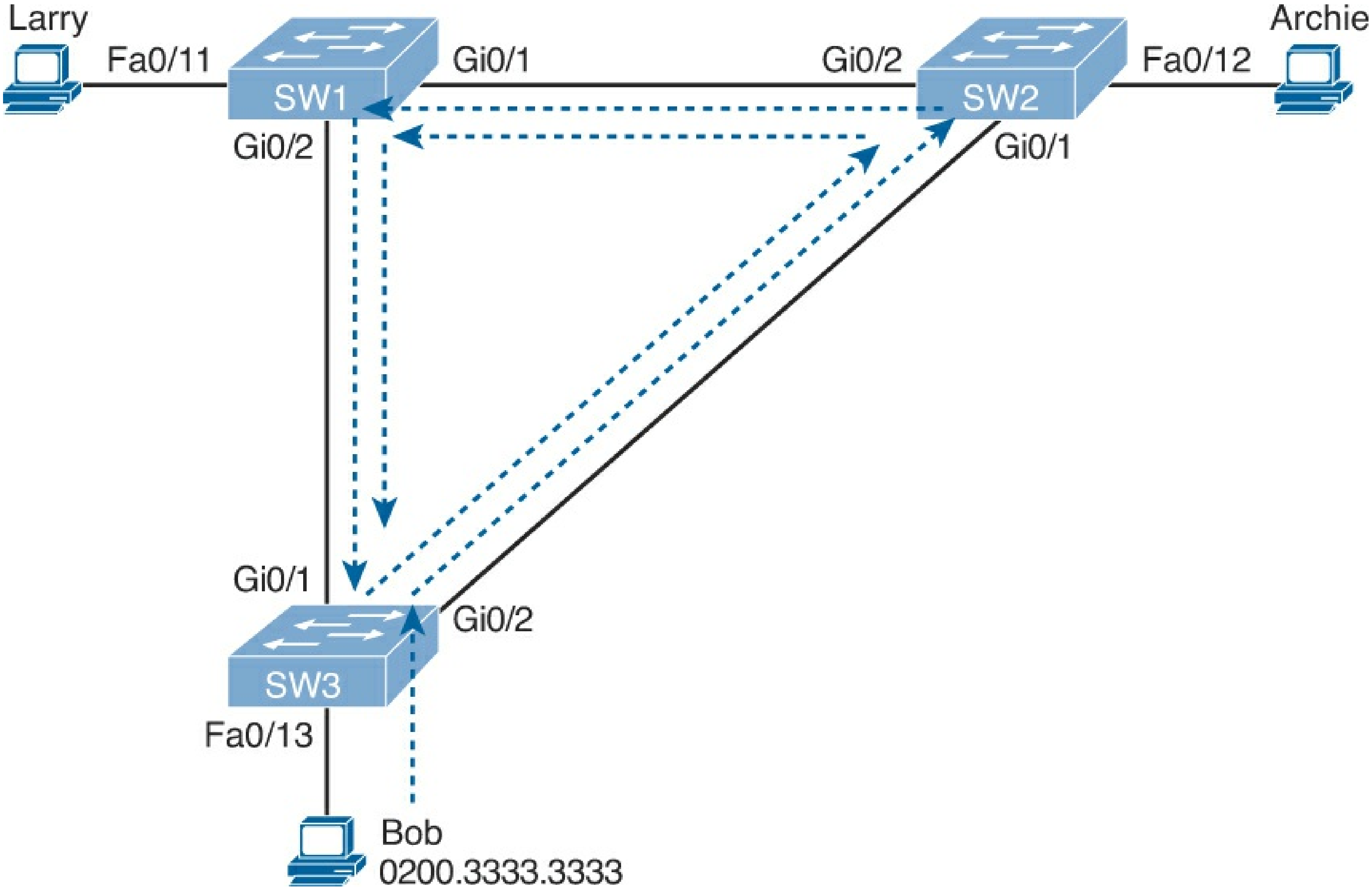


Figure 1-3. Broadcast Storm

Note

Bob's original broadcast would also be forwarded around the other direction as well, with SW3 sending a copy of the original frame out its Gi0/1 port. The figure does not show that frame just to reduce the clutter.

Remember that LAN switch logic that was reviewed earlier in the chapter? That logic tells switches to flood broadcasts out all interfaces in the same VLAN except the interface in which the frame arrived. In the figure, that means SW3 forwards Bob's frame to SW2, SW2 forwards the frame to SW1, SW1 forwards the frame back to SW3, and SW3 forwards it back to SW2 again.

When broadcast storms happen, frames like the one in Figure 1-3 keep looping until something changes—someone shuts down an interface, reloads a switch, or does something else to break the loop. Also note that the same event happens in the opposite direction. When Bob sends the original frame, SW3 also forwards a copy to SW1, SW1 forwards it to SW2, and so on.

Looping frames also cause a MAC table instability problem. MAC table instability means that the switches' MAC address tables keep changing the information listed for the source MAC address of the looping frame. For example, SW3 begins Figure 1-3 with a MAC table entry for Bob, at the bottom of the figure, as follows:

```
0200.3333.3333 Fa0/13 VLAN 1
```

However, now think about the switch-learning process that occurs when the looping frame goes to SW2, then SW1, and then back into SW3's Gi0/1 interface. SW3 thinks, "Hmm... the source MAC address is 0200.3333.3333, and it came in my Gi0/1 interface. Update my MAC table!" resulting in the following entry on SW3:

```
0200.3333.3333 Gi0/1 VLAN 1
```

At this point, SW3 itself cannot correctly deliver frames to Bob's MAC address. At that instant, if a frame arrives at SW3 destined for Bob—a different frame than the looping frame that causes the problems—SW3 incorrectly forwards the frame out Gi0/1 to SW1.

The looping frames also cause a third problem: multiple copies of the frame arrive at the destination. Consider a case in which

Bob sends a frame to Larry but none of the switches know Larry’s MAC address. Switches flood frames sent to unknown destination unicast MAC addresses. When Bob sends the frame destined for Larry’s MAC address, SW3 sends a copy to both SW1 and SW2. SW1 and SW2 also flood the frame, causing copies of the frame to loop. SW1 also sends a copy of each frame out Fa0/11 to Larry. As a result, Larry gets multiple copies of the frame, which may result in an application failure, if not more pervasive networking problems.

Table 1-2 summarizes the main three classes of problems that occur when STP is not used in a LAN with redundancy.

Key Topic

Table 1-2. Three Classes of Problems Caused by Not Using STP in Redundant LANs

Problem	Description
Broadcast storms	The forwarding of a frame repeatedly on the same links, consuming significant parts of the links’ capacities
MAC table instability	The continual updating of a switch’s MAC address table with incorrect entries, in reaction to looping frames, resulting in frames being sent to the wrong locations
Multiple frame transmission	A side effect of looping frames in which multiple copies of one frame are delivered to the intended host, confusing the host

What IEEE 802.1D Spanning Tree Does

STP prevents loops by placing each switch port in either a forwarding state or a blocking state. Interfaces in the forwarding state act as normal, forwarding and receiving frames. However, interfaces in a blocking state do not process any frames except STP messages (and some other overhead messages). Interfaces that block do not forward user frames, do not learn MAC addresses of received frames, and do not process received user frames.

Figure 1-4 shows a simple STP tree that solves the problem shown in Figure 1-3 by placing one port on SW3 in the blocking state.

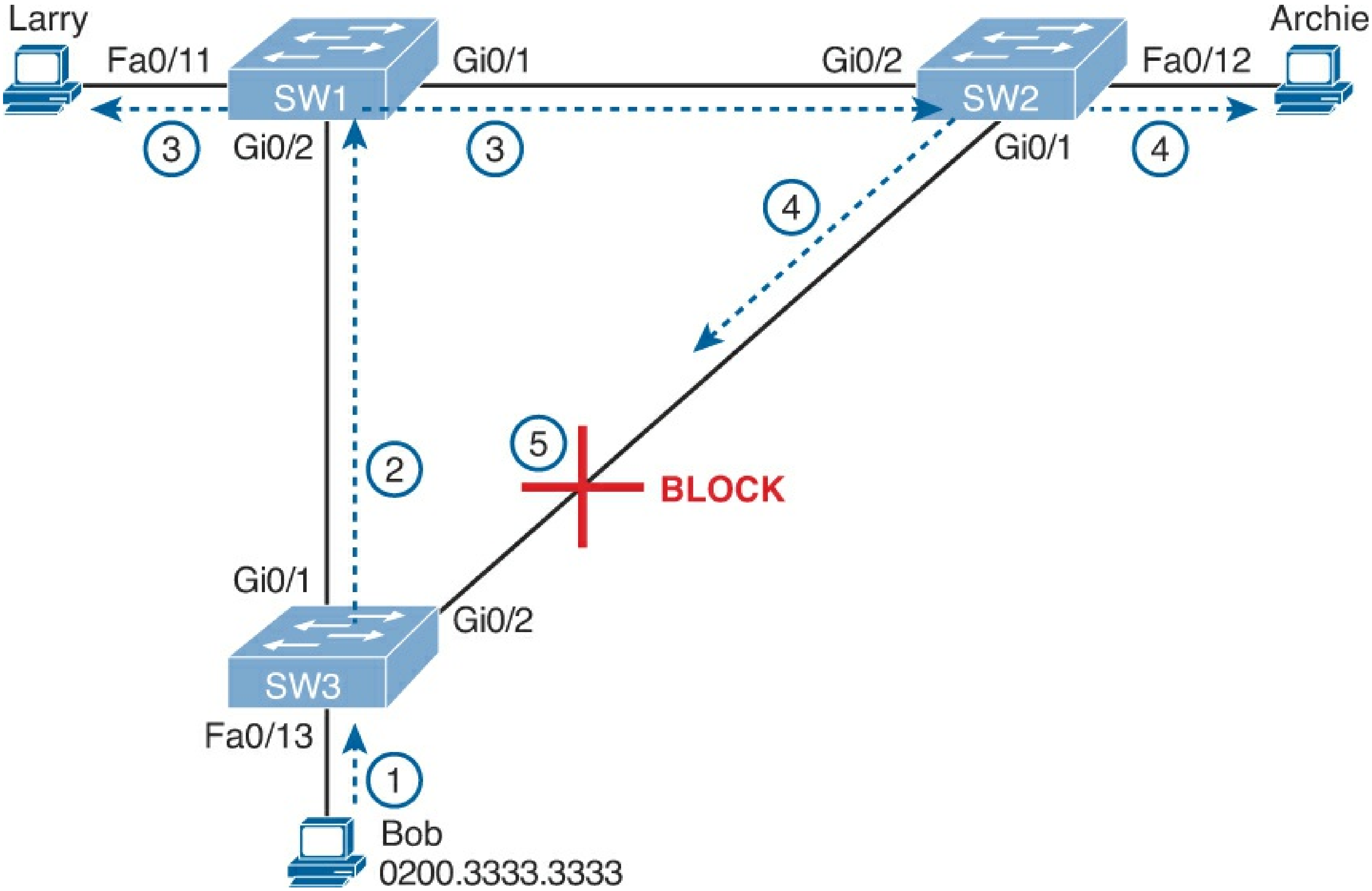


Figure 1-4. What STP Does: Blocks a Port to Break the Loop

Now when Bob sends a broadcast frame, the frame does not loop. As shown in the steps in the figure:

Step 1. Bob sends the frame to SW3.

Step 2. SW3 forwards the frame only to SW1, but not out Gi0/2 to SW2, because SW3's Gi0/2 interface is in a blocking state.

Step 3. SW1 floods the frame out both Fa0/11 and Gi0/1.

Step 4. SW2 floods the frame out Fa0/12 and Gi0/1.

Step 5. SW3 physically receives the frame, but it ignores the frame received from SW2 because SW3's Gi0/2 interface is in a blocking state.

With the STP topology in Figure 1-4, the switches simply do not use the link between SW2 and SW3 for traffic in this VLAN, which is the minor negative side effect of STP. However, if either of the other two links fails, STP converges so that SW3 forwards instead of blocks on its Gi0/2 interface.

> **Note**
>
> The term *STP convergence* refers to the process by which the switches collectively realize that something has changed in the LAN topology and so the switches might need to change which ports block and which ports forward.

That completes the description of what STP does, placing each port into either a forwarding or blocking state. The more interesting question, and the one that takes a lot more work to understand, is the question of how and why STP makes its choices. How does STP manage to make switches block or forward on each interface? And how does it converge to change state from blocking to forwarding to take advantage of redundant links in response to network outages? The following sections answer these questions.

How Spanning Tree Works

The STP algorithm creates a spanning tree of interfaces that forward frames. The tree structure of forwarding interfaces creates a single path to and from each Ethernet link, just like you can trace a single path in a living, growing tree from the base of the tree to each leaf.

> **Note**
>
> STP was created before LAN switches even existed. In those days, Ethernet bridges used STP. Today, switches play the same role as bridges, implementing STP. However, many STP terms still refer to bridge. For the purposes of STP and this chapter, consider the terms *bridge* and *switch* synonymous.

The process used by STP, sometimes called the *spanning-tree algorithm* (STA), chooses the interfaces that should be placed into a forwarding state. For any interfaces not chosen to be in a forwarding state, STP places the interfaces in blocking state. In other words, STP simply picks which interfaces should forward, and any interfaces left over go to a blocking state.

STP uses three criteria to choose whether to put an interface in forwarding state:

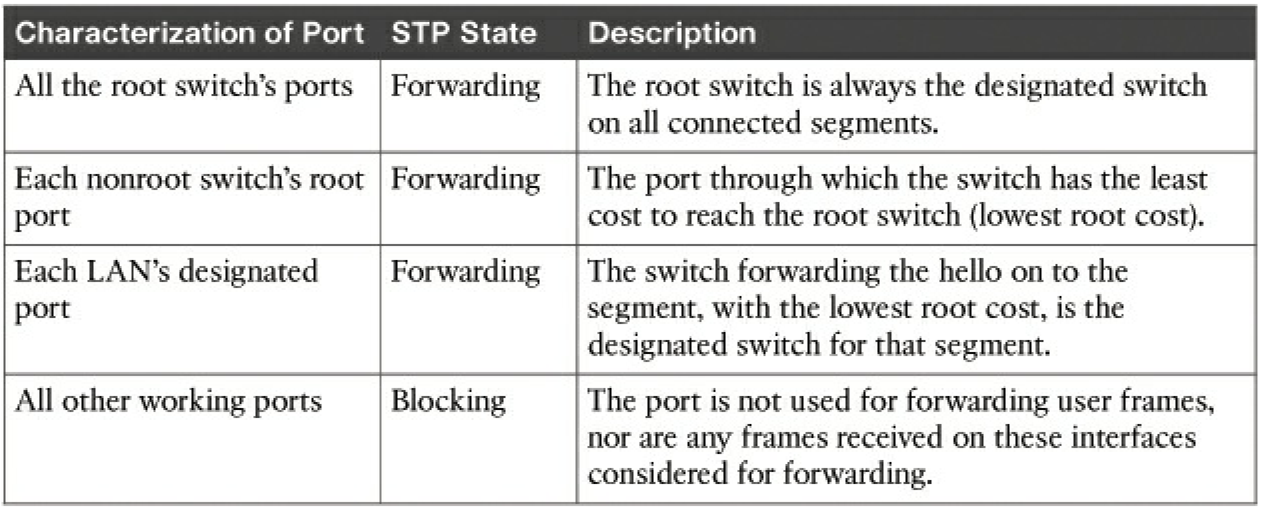
- STP elects a root switch. STP puts all working interfaces on the root switch in forwarding state.
- Each nonroot switch considers one of its ports to have the least administrative cost between itself and the root switch. The cost is called that switch's *root cost*. STP places its port that is part of the least root cost path, called that switch's *root port* (RP), in forwarding state.
- Many switches can attach to the same Ethernet segment, but in modern networks, normally two switches connect to each link. The switch with the lowest root cost, as compared with the other switches attached to the same link, is placed in forwarding state. That switch is the designated switch, and that switch's interface, attached to that segment, is called the *designated port* (DP).

> **Note**
>
> The real reason the root switches places all working interfaces in a forwarding state is that all its interfaces will become DPs, but it is easier to just remember that all the root switches' working interfaces will forward frames.

All other interfaces are placed in blocking state. Table 1-3 summarizes the reasons STP places a port in forwarding or blocking state.

Key Topic

Table 1-3. STP: Reasons for Forwarding or Blocking



Characterization of Port	STP State	Description
All the root switch's ports	Forwarding	The root switch is always the designated switch on all connected segments.
Each nonroot switch's root port	Forwarding	The port through which the switch has the least cost to reach the root switch (lowest root cost).
Each LAN's designated port	Forwarding	The switch forwarding the hello on to the segment, with the lowest root cost, is the designated switch for that segment.
All other working ports	Blocking	The port is not used for forwarding user frames, nor are any frames received on these interfaces considered for forwarding.

Note

STP only considers working interfaces (those in a connected state). Failed interfaces (for example, interfaces with no cable installed) or administratively shutdown interfaces are instead placed into an STP disabled state. So, this section uses the term *working ports* to refer to interfaces that could forward frames if STP placed the interface into a forwarding state.

The STP Bridge ID and Hello BPDU

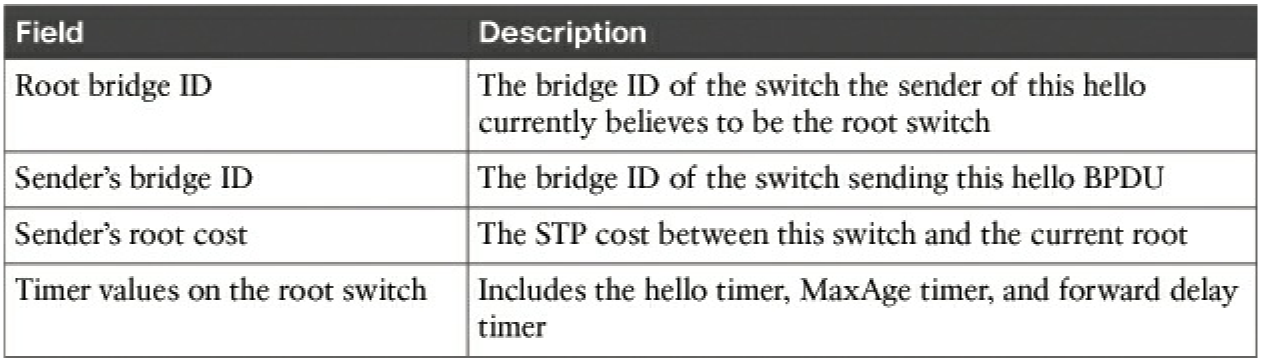
The STA begins with an election of one switch to be the root switch. To better understand this election process, you need to understand the STP messages sent between switches as well as the concept and format of the identifier used to uniquely identify each switch.

The STP bridge ID (BID) is an 8-byte value unique to each switch. The bridge ID consists of a 2-byte priority field and a 6-byte system ID, with the system ID being based on a universal (burned-in) MAC address in each switch. Using a burned-in MAC address ensures that each switch's bridge ID will be unique.

STP defines messages called *bridge protocol data units* (BPDU), which switches use to exchange information with each other. The most common BPDU, called a hello BPDU, lists many details, including the sending switch's BID. By listing its own unique BID, switches can tell which switch sent which hello BPDU. Table 1-4 lists some of the key information in the hello BPDU.

Key Topic

Table 1-4. Fields in the STP Hello BPDU



Field	Description
Root bridge ID	The bridge ID of the switch the sender of this hello currently believes to be the root switch
Sender's bridge ID	The bridge ID of the switch sending this hello BPDU
Sender's root cost	The STP cost between this switch and the current root
Timer values on the root switch	Includes the hello timer, MaxAge timer, and forward delay timer

For the time being, just keep the first three items from Table 1-4 in mind as the following sections work through the three steps in how STP chooses the interfaces to place into a forwarding state. Next, the text examines the three main steps in the STP process.

Electing the Root Switch

Switches elect a root switch based on the BIDs in the BPDUs. The root switch is the switch with the lowest numeric value for the BID. Because the two-part BID starts with the priority value, essentially the switch with the lowest priority becomes the root. For example, if one switch has priority 4096, and another switch has priority 8192, the switch with priority 4096 wins, regardless of what MAC address was used to create the BID for each switch.

If a tie occurs based on the priority portion of the BID, the switch with the lowest MAC address portion of the BID is the root. No other tiebreaker should be needed because switches use one of their own universal (burned-in) MAC addresses as the second part of their BIDs. So if the priorities tie, and one switch uses a MAC address of 0200.0000.0000 as part of the BID and the other uses 0911.1111.1111, the first switch (MAC 0200.0000.0000) becomes the root switch.

STP elects a root switch in a manner not unlike a political election. The process begins with all switches claiming to be the root by sending hello BPDUs listing their own BID as the root BID. If a switch hears a hello that lists a better (lower) BID, that switch stops advertising itself as root and starts forwarding the superior hello. The hello sent by the better switch lists the better switch's BID as the root. It works like a political race in which a less-popular candidate gives up and leaves the race, throwing his support behind the more popular candidate. Eventually, everyone agrees which switch has the best (lowest) BID, and everyone supports the elected switch—which is where the political race analogy falls apart.

Note

A better hello, meaning that the listed root's BID is better (numerically lower), is called a *superior hello*; a worse hello, meaning that the listed root's BID is not as good (numerically higher), is called an *inferior hello*.

Figure 1-5 shows the beginning of the root election process. In this case, SW1 has advertised itself as root, as have SW2 and SW3. However, SW2 now believes that SW1 is a better root, so SW2 is now forwarding the hello originating at SW1. So, at this point, the figure shows SW1 is saying hello, claiming to be root; SW2 agrees, and is forwarding SW1's hello that lists SW1 as root; but, SW3 is still claiming to be best, sending his own hello BPDUs, listing SW3's BID as the root.

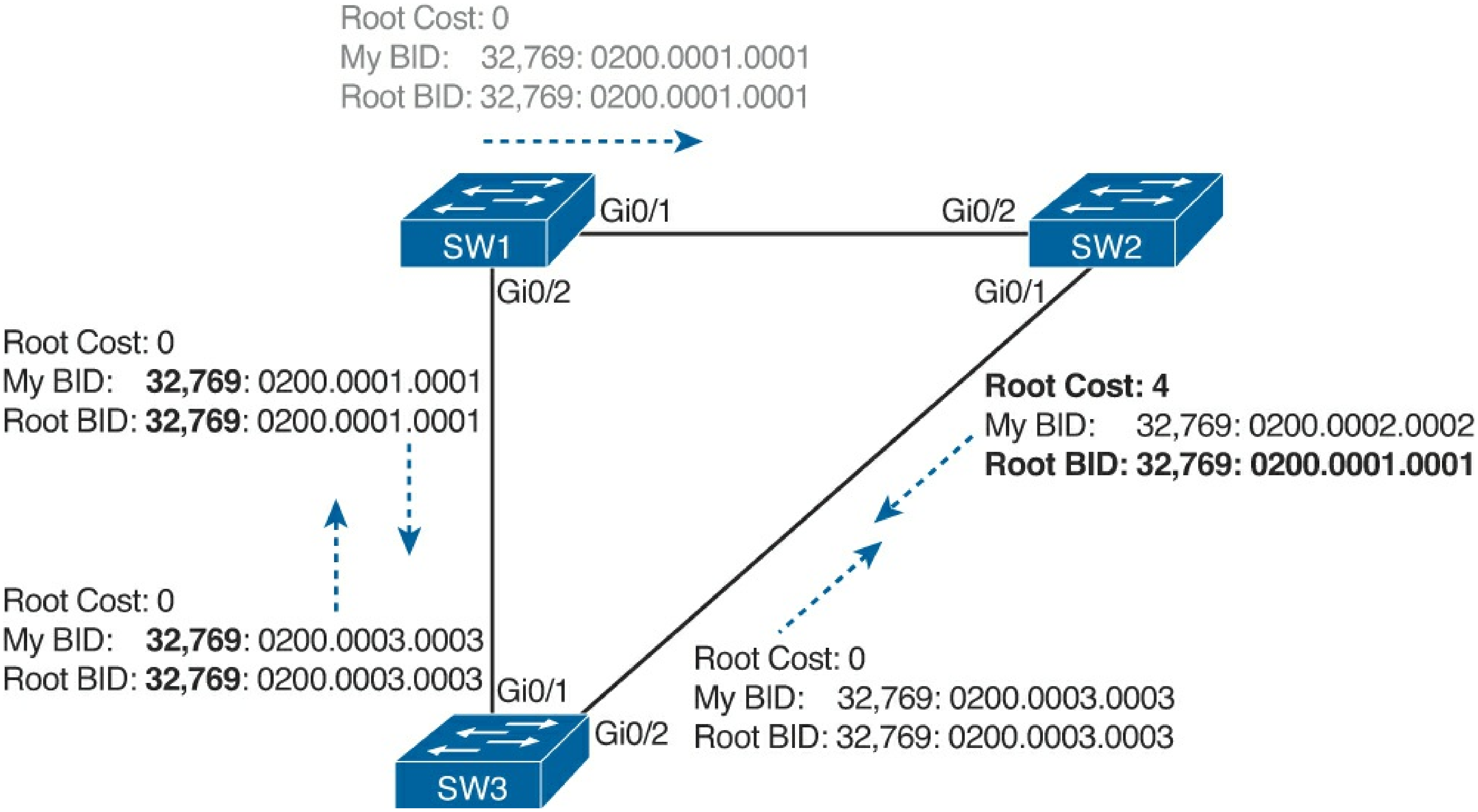

Root Cost: 0
My BID: 32,769: 0200.0001.0001
Root BID: 32,769: 0200.0001.0001
SW1
Gi0/1
Gi0/2
SW2
Gi0/2
Gi0/1
Root Cost: 0
My BID: **32,769**: 0200.0001.0001
Root BID: **32,769**: 0200.0001.0001
Root Cost: 4
My BID: 32,769: 0200.0002.0002
Root BID: 32,769: 0200.0001.0001
Root Cost: 0
My BID: **32,769**: 0200.0003.0003
Root BID: **32,769**: 0200.0003.0003
Gi0/1
Gi0/2
SW3
Root Cost: 0
My BID: 32,769: 0200.0003.0003
Root BID: 32,769: 0200.0003.0003

Figure 1-5. Beginnings of the Root Election Process

Two candidates still exist in Figure 1-5: SW1 and SW3. So who wins? Well, from the BID, the lower-priority switch wins; if a tie occurs, the lower MAC address wins. As shown in the figure, SW1 has a lower BID (32769:0200.0000.0001) than SW3 (32769:0200.0003.0003), so SW1 wins, and SW3 now also believes that SW1 is the better switch. Figure 1-6 shows the resulting hello messages sent by the switches.

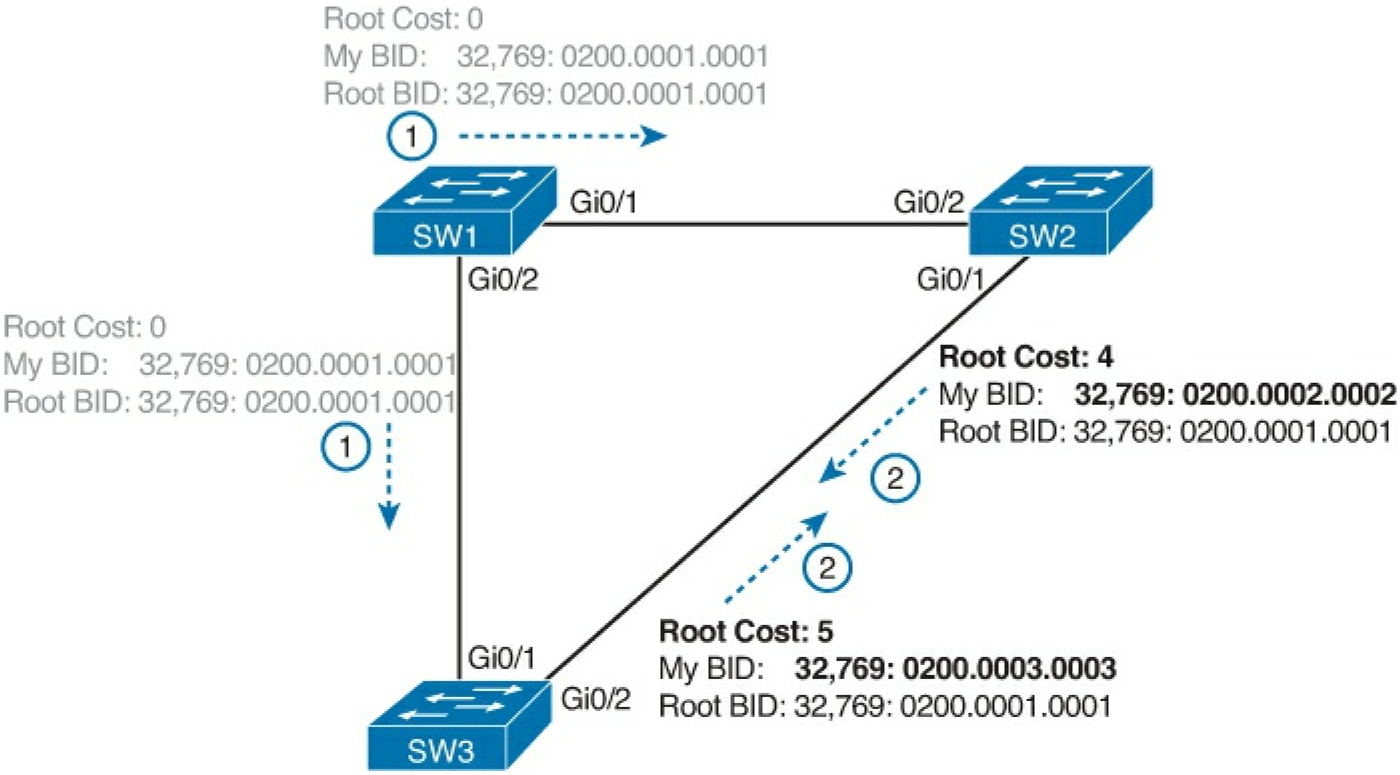

Root Cost: 0
My BID: 32,769: 0200.0001.0001
Root BID: 32,769: 0200.0001.0001
1
SW1
Gi0/1
Gi0/2
SW2
Gi0/2
Gi0/1
Root Cost: 0
My BID: 32,769: 0200.0001.0001
Root BID: 32,769: 0200.0001.0001
1
Root Cost: 4
My BID: 32,769: 0200.0002.0002
Root BID: 32,769: 0200.0001.0001
2
2
Root Cost: 5
My BID: 32,769: 0200.0003.0003
Root BID: 32,769: 0200.0001.0001
Gi0/1
Gi0/2
SW3

Figure 1-6. SW1 Wins the Election

After the election is complete, only the root switch continues to originate STP hello BPDU messages. The other switches receive the hellos, update the sender's BID field (and root cost field), and forward the hellos out other interfaces. The figure reflects this fact, with SW1 sending hellos at Step 1, and SW2 and SW3 independently forwarding the hello out their other interfaces at Step 2.

Summarizing, the root election happens through each switch claiming to be root, with the best switch being elected based on the numerically lowest BID. Breaking down the BID into its components, the comparisons can be made as

Key Topic

- The lowest bridge ID
- If that ties, the lowest switch MAC address

Choosing Each Switch's Root Port

The second part of the STP process occurs when each nonroot switch chooses its one and only *root port*. A switch's RP is its interface through which it has the least STP cost to reach the root switch (least root cost).

The idea of a switch's cost to reach the root switch can be easily seen for humans. Just look at a network diagram that shows the root switch, lists the STP cost associated with each switch port, and the nonroot switch in question. Switches use a different process than looking at a network diagram, of course, but using a diagram can make it easier to learn the idea.

Figure 1-7 shows just such a figure, with the same three switches shown in the last several figures. SW1 has already won the election as root, and the figure considers the cost from SW3's perspective.

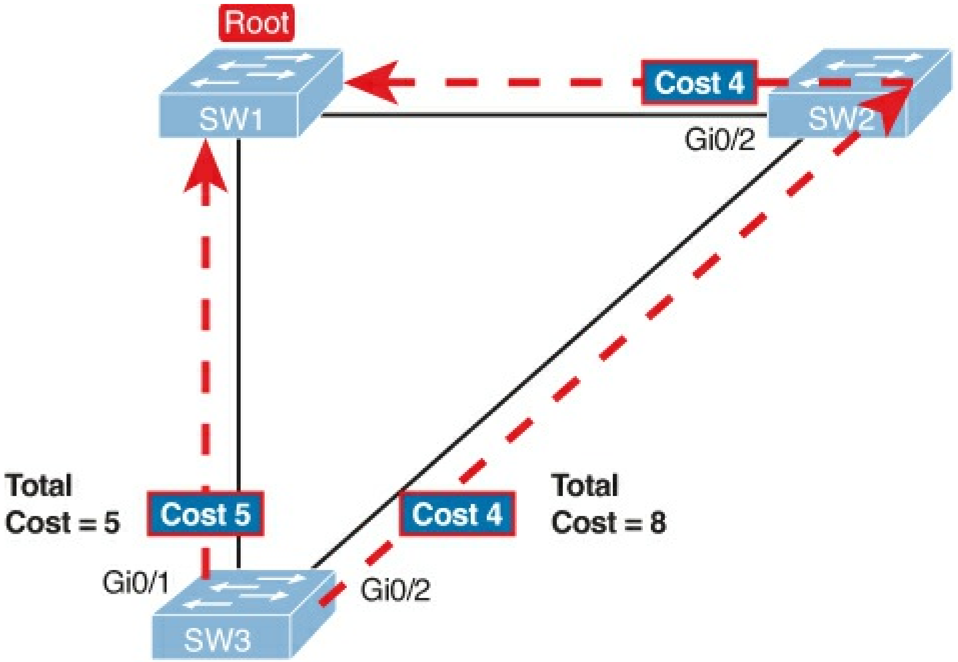

Root
SW1
Cost 4
SW2
Gi0/2
Total
Cost = 5
Cost 5
Cost 4
Total
Cost = 8
Gi0/1
Gi0/2
SW3

Figure 1-7. How a Human Might Calculate STP Cost from SW3 to the Root (SW1)

SW3 has two possible physical paths to send frames to the root switch: the direct path to the left, and the indirect path to the right through switch SW2. The cost is the sum of the costs of all the *switch ports the frame would exit* if it flowed over that path. (The calculation ignores the inbound ports.) As you can see, the cost over the direct path out SW3's G0/1 port has a total cost of 5, and the other path has a total cost of 8. SW3 picks its G0/1 port as root port because it is the port that is part of the least-cost path to send frames to the root switch.

Switches come to the same conclusion, but using a different process. Instead, they add their local interface STP cost to the root cost listed in each received hello BPDU. The STP port cost is simply an integer value assigned to each interface, per VLAN, for the purpose of providing an objective measurement that allows STP to choose which interfaces to add to the STP topology. The switches also look at their neighbor's root cost, as announced in hello BPDUs received from each neighbor.

Figure 1-8 shows an example of how switches calculate their best root cost and then choose their root port, using the same topology and STP costs as shown in Figure 1-7. STP on SW3 calculates its cost to reach the root over the two possible paths by adding the advertised cost (in hello messages) to the interface costs listed in the figure.

Key Topic

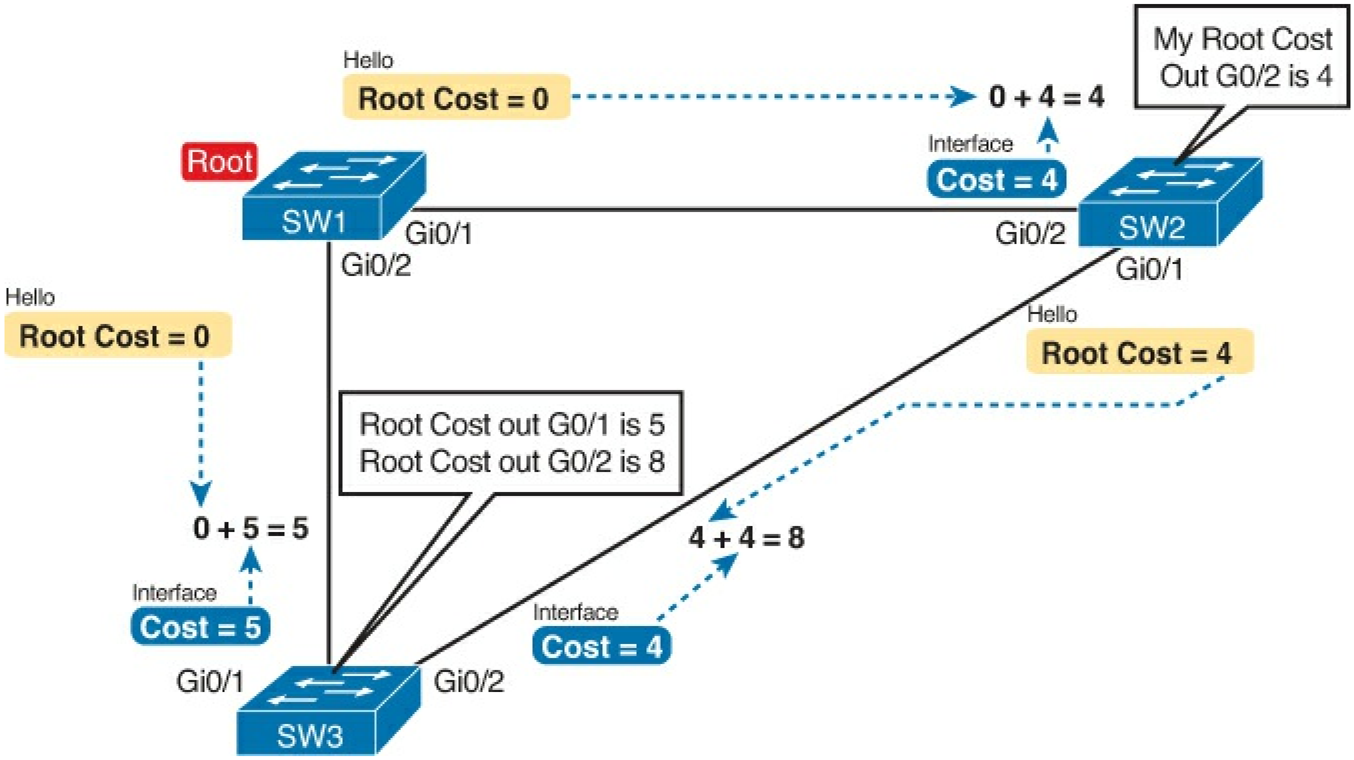

Hello
Root Cost = 0
0 + 4 = 4
My Root Cost
Out G0/2 is 4
Root
Interface
Cost = 4
SW1
Gi0/1
Gi0/2
Gi0/2
SW2
Gi0/1
Hello
Root Cost = 0
Hello
Root Cost = 4
Root Cost out G0/1 is 5
Root Cost out G0/2 is 8
0 + 5 = 5
4 + 4 = 8
Interface
Cost = 5
Interface
Cost = 4
Gi0/1
Gi0/2
SW3

Figure 1-8. How STP Actually Calculates the Cost from SW3 to the Root

Focus on the process for a moment. The root switch sends hellos, with a listed root cost of 0. The idea is that the root's cost to reach itself is 0.

Next, look on the left of the figure. SW3 takes the received cost (0) from the hello sent by SW1, adds the interface cost (5) of the interface on which that hello was received. SW3 calculates that the cost to reach the root switch, out that port (G0/1), is 5.

On the right side, SW2 has realized its best cost to reach the root is cost 4. So, when SW2 forwards the hello toward SW3, SW2 lists a root cost 4. SW3's STP port cost on port G0/2 is 4, so SW3 determines a total cost to reach root out its G0/2 port of 8.

As a result of the process depicted in Figure 1-8, SW3 chooses Gi0/1 as its RP, because the cost to reach the root switch through that port (5) is lower than the other alternative (Gi0/2, cost 8). Similarly, SW2 chooses Gi0/2 as its RP, with a cost of 4 (SW1's advertised cost of 0 plus SW2's Gi0/2 interface cost of 4). Each switch places its root port into a forwarding state.

In more complex topologies, the choice of root port will not be so obvious. The section "STP Troubleshooting" in Chapter 2 discusses these more complex examples, including the tiebreakers to use if the root costs tie.

Choosing the Designated Port on Each LAN Segment

STP's final step to choose the STP topology is to choose the designated port on each LAN segment. The designated port (DP) on each LAN segment is the switch port that advertises the lowest-cost hello onto a LAN segment. When a nonroot switch forwards a hello, the nonroot switch sets the root cost field in the hello to that switch's cost to reach the root. In effect, the switch with the lower cost to reach the root, among all switches connected to a segment, becomes the DP on that segment.

For example, earlier Figure 1-6 shows in bold text the parts of the hello messages from both SW2 and SW3 that determine the choice of DP on that segment. Note that both SW2 and SW3 list their respective cost to reach the root switch (cost 4 on SW2 and cost 5 on SW3). SW2 lists the lower cost, so SW2's Gi0/1 port is the designated port on that LAN segment.

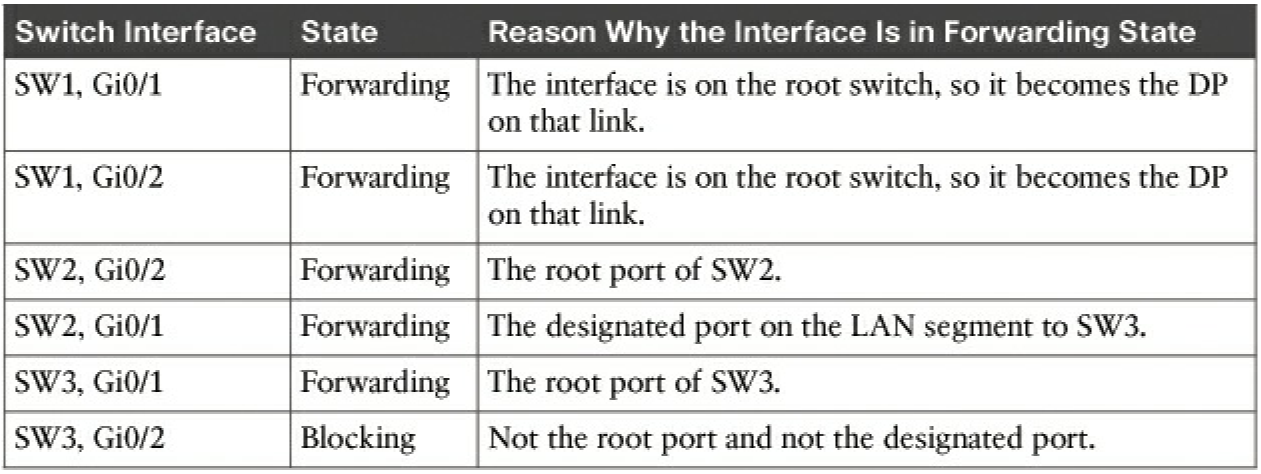
All DPs are placed into a forwarding state; so in this case, SW2's Gi0/1 interface will be in a forwarding state.

If the advertised costs tie, the switches break the tie by choosing the switch with the lower BID. In this case, SW2 would also have won, with a BID of 32769:0200.0002.0002 versus SW3's 32769:0200.0003.0003.

> **Note**
>
> Two additional tiebreakers are needed in some cases, although these would be unlikely today. A single switch can connect two or more interfaces to the same collision domain by connecting to a hub. In that case, the one switch hears its own BPDUs. So, if a switch ties with itself, two additional tiebreakers are used: the lowest interface STP priority and, if that ties, the lowest internal interface number.

The only interface that does not have a reason to be in a forwarding state on the three switches in the examples shown in Figures 1-5 through 1-8 is SW3's Gi0/2 port. So, the STP process is now complete. Table 1-5 outlines the state of each port and shows why it is in that state.

Table 1-5. State of Each Interface



Switch Interface	State	Reason Why the Interface Is in Forwarding State
SW1, Gi0/1	Forwarding	The interface is on the root switch, so it becomes the DP on that link.
SW1, Gi0/2	Forwarding	The interface is on the root switch, so it becomes the DP on that link.
SW2, Gi0/2	Forwarding	The root port of SW2.
SW2, Gi0/1	Forwarding	The designated port on the LAN segment to SW3.
SW3, Gi0/1	Forwarding	The root port of SW3.
SW3, Gi0/2	Blocking	Not the root port and not the designated port.

Influencing and Changing the STP Topology

Switches do not just use STP once and never again. The switches continually watch for changes. Those changes can be because a link or switch fails or it can be a new link that can now be used. The configuration can change in a way that changes the STP topology. This section briefly discusses the kinds of things that change the STP topology, either through configuration or through changes in the status of devices and links in the LAN.

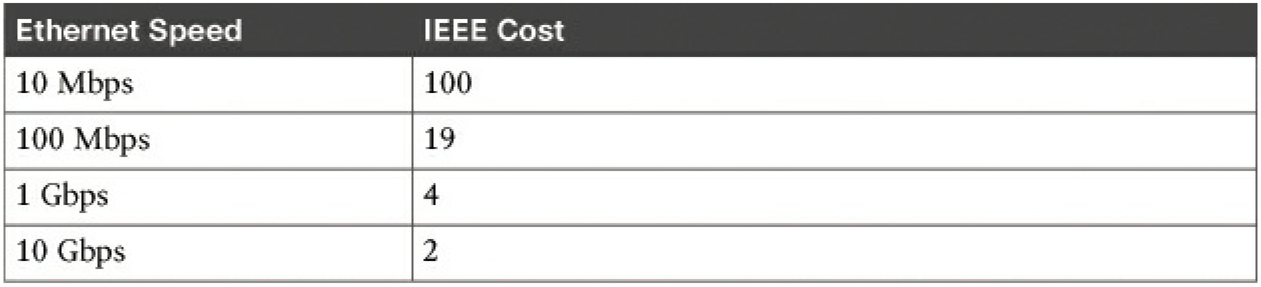
Making Configuration Changes to Influence the STP Topology

The network engineers can choose to change the STP settings to then change the choices STP makes in a given LAN. Two main tools available to the engineer are to configure the bridge ID and to change STP port costs.

Switches have a way to create a default BID, by taking a default priority value, and adding a universal MAC address that comes with the switch hardware. However, engineers typically want to choose which switch becomes the root. Chapter 2 shows how to configure a Cisco switch to override its default BID setting to make a switch become root.

Port costs also have default values, per port, per VLAN. You can configure these port costs, or you can use the default values. Table 1-6 lists the default port costs defined by IEEE; Cisco uses these same defaults.

Table 1-6. Default Port Costs According to IEEE



Ethernet Speed	IEEE Cost
10 Mbps	100
100 Mbps	19
1 Gbps	4
10 Gbps	2

With STP enabled, all working switch interfaces will settle into an STP forwarding or blocking state, even access ports. For switch interfaces connected to hosts or routers, which do not use STP, the switch still forwards hellos on to those interfaces. By virtue of being the only device sending a hello onto that LAN segment, the switch is sending the least-cost hello on to that LAN segment, making the switch become the designated port on that LAN segment. So, STP puts working access interfaces into a forwarding state as a result of the designated port part of the STP process.

Reacting to State Changes That Affect the STP Topology

Once the engineer has finished all STP configuration, the STP topology should settle into a stable state and not change, at least until the network topology changes. This section examines the ongoing operation of STP while the network is stable, and then it covers how STP converges to a new topology when something changes.

The root switch sends a new hello BPDU every 2 seconds by default. Each nonroot switch forwards the hello on all DPs, but only after changing items listed in the hello. The switch sets the root cost to that local switch's calculated root cost. The switch also sets the "sender's bridge ID" field to its own bridge ID. (The root's bridge ID field is not changed.)

By forwarding the received (and changed) hellos out all DPs, all switches continue to receive hellos every 2 seconds. The following steps summarize the steady-state operation when nothing is currently changing in the STP topology:

Step 1. The root creates and sends a hello BPDU, with a root cost of 0, out all its working interfaces (those in a forwarding state).

Step 2. The nonroot switches receive the hello on their root ports. After changing the hello to list their own BID as the sender's BID, and listing that switch's root cost, the switch forwards the hello out all designated ports.

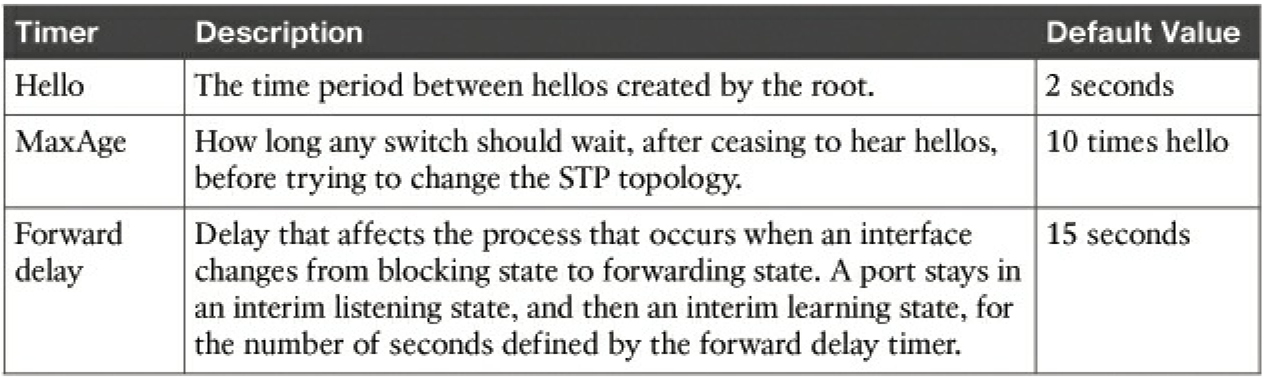
Step 3. Steps 1 and 2 repeat until something changes.

Each switch relies on these periodic received hellos from the root as a way to know that its path to the root is still working. When a switch ceases to receive the hellos, or receives a hello that lists different details, something has failed, so the switch reacts and starts the process of changing the spanning-tree topology.

How Switches React to Changes with STP

For various reasons, the convergence process requires the use of three timers. Note that all switches use the timers as dictated by the root switch, which the root lists in its periodic hello BPDU messages. Table 1-7 describes the timers.

Table 1-7. STP Timers



Timer	Description	Default Value
Hello	The time period between hellos created by the root.	2 seconds
MaxAge	How long any switch should wait, after ceasing to hear hellos, before trying to change the STP topology.	10 times hello
Forward delay	Delay that affects the process that occurs when an interface changes from blocking state to forwarding state. A port stays in an interim listening state, and then an interim learning state, for the number of seconds defined by the forward delay timer.	15 seconds

If a switch does not get an expected hello BPDU within the hello time, the switch continues as normal. However, if the hellos do not show up again within MaxAge time, the switch reacts by taking steps to change the STP topology. With default settings, MaxAge is 20 seconds (10 times the default hello timer of 2 seconds). So, a switch would go 20 seconds without hearing a hello before reacting.

After MaxAge expires, the switch essentially makes all its STP choices again, based on any hellos it receives from other switches. It reevaluates which switch should be the root switch. If the local switch is not the root, it chooses its RP. And it determines whether it is DP on each of its other links. The best way to describe STP convergence is to show an example using the same familiar topology. Figure 1-9 shows the same familiar figure, with SW3's Gi0/2 in a blocking state, but SW1's Gi0/2 interface has just failed.

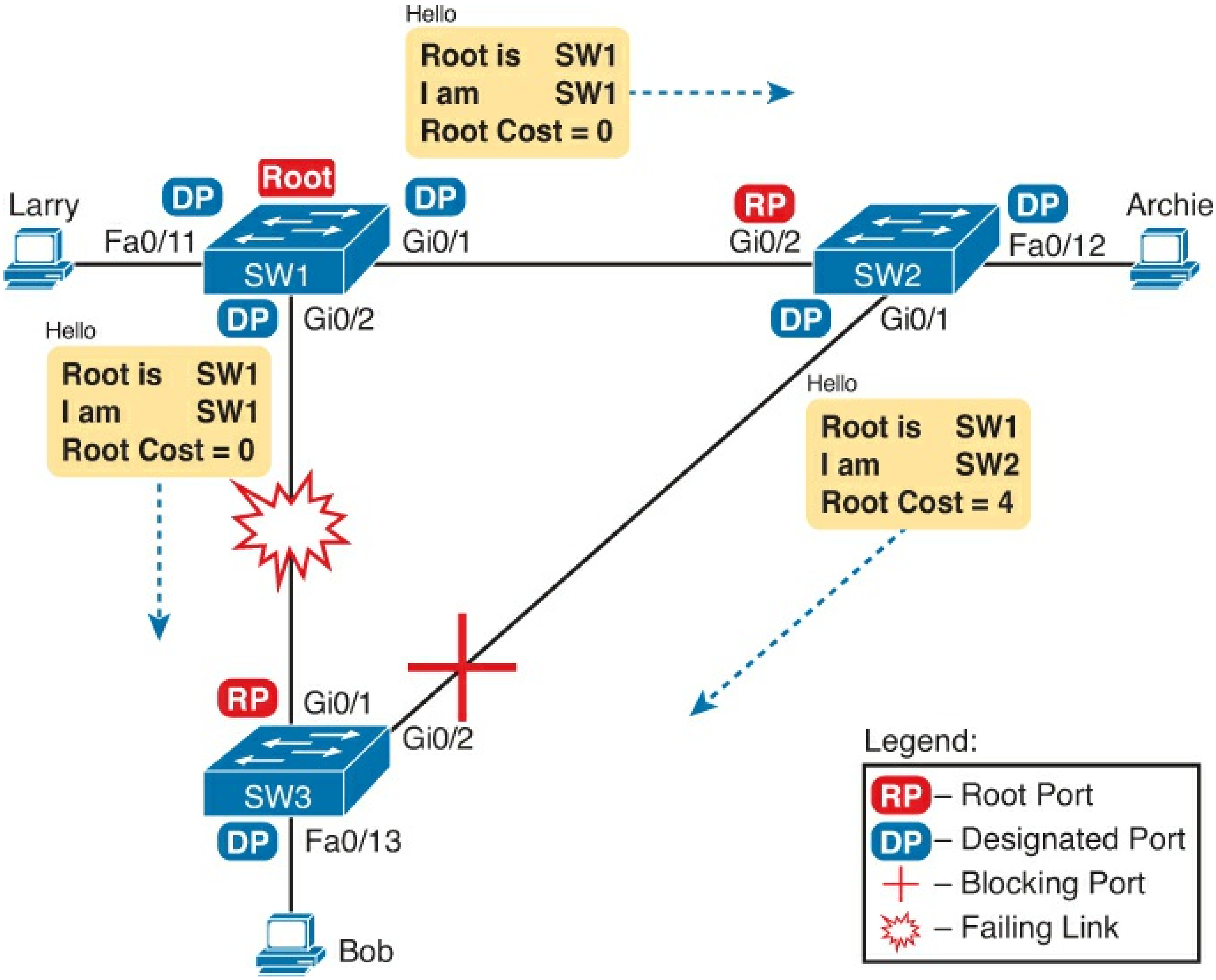


Figure 1-9. Initial STP State Before SW1-SW3 Link Fails

SW3 reacts to the change because SW3 fails to receive its expected hellos on its Gi0/1 interface. However, SW2 does not need to react because SW2 continues to receive its periodic hellos in its Gi0/2 interface. In this case, SW3 reacts either when MaxAge time passes without hearing the hellos, or as soon as SW3 notices that interface Gi0/1 has failed. (If the interface fails, the switch can assume that the hellos will not be arriving in that interface anymore.)

Now that SW3 can act, it begins by reevaluating the choice of root switch. SW3 still receives the hellos from SW2, as forwarded from the root (SW1). SW1 still has a lower BID than SW3; otherwise, SW1 would not have already been the root. So, SW3 decides that SW1 is still the best switch and that SW3 is not the root.

Next, SW3 reevaluates its choice of RP. At this point, SW3 is receiving hellos on only one interface: Gi0/2. Whatever the calculated root cost, Gi0/2 becomes SW3's new RP. (The cost would be 8, assuming the STP costs had no changes since Figures 1-7 and 1-8.)

SW3 then reevaluates its role as DP on any other interfaces. In this example, no real work needs to be done. SW3 was already DP on interface Fa0/13, and it continues to be the DP because no other switches connect to that port.

Changing Interface States with STP

STP uses the idea of roles and states. Roles, like root port and designated port, relate to how STP analyzes the LAN topology. States, like forwarding and blocking, tell a switch whether to send or receive frames. When STP converges, a switch chooses new port roles, and the port roles determine the state (forwarding or blocking).

Switches can simply move immediately from forwarding to blocking state, but they must take extra time to transition from blocking state to forwarding state. For instance, when a switch formerly used port G0/1 as its RP (a role), that port was in a forwarding state. After convergence, G0/1 might be neither an RP nor DP; the switch can immediately move that port to a blocking state.

When a port that formerly blocked needs to transition to forwarding, the switch first puts the port through two intermediate interface states. These temporary states help prevent temporary loops:

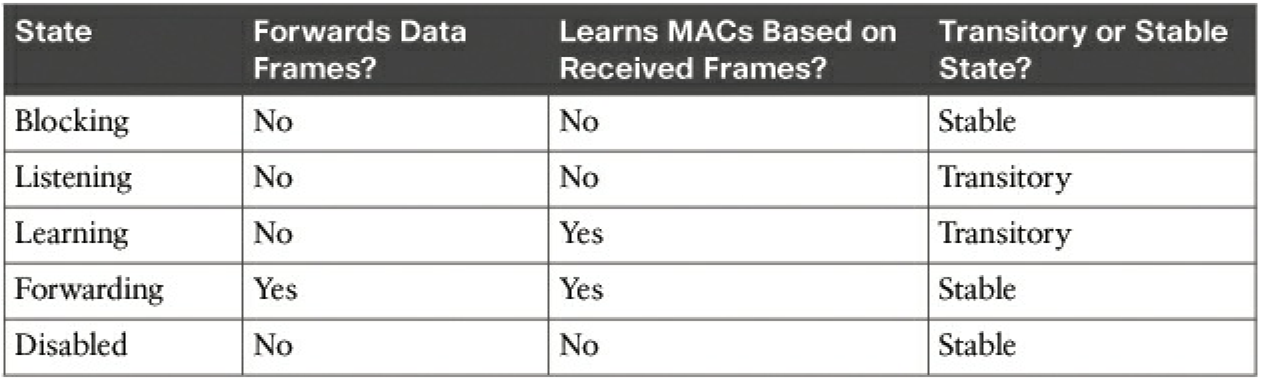
- **Listening:** Like the blocking state, the interface does not forward frames. The switch removes old stale (unused) MAC table entries for which no frames are received from each MAC address during this period. These stale MAC table entries could be the cause of the temporary loops.
- **Learning:** Interfaces in this state still do not forward frames, but the switch begins to learn the MAC addresses of frames received on the interface.

STP moves an interface from blocking to listening, then to learning, and then to forwarding state. STP leaves the interface in each interim state for a time equal to the forward delay timer, which defaults to 15 seconds. As a result, a convergence event that causes an interface to change from blocking to forwarding requires 30 seconds to transition from blocking to forwarding. In addition, a switch might have to wait MaxAge seconds before even choosing to move an interface from blocking to forwarding state.

For example, follow what happens with an initial STP topology as shown in Figures 1-5 through 1-8, with the SW1-to-SW3 link failing as shown in Figure 1-9. If SW1 simply quit sending hello messages to SW3, but the link between the two did not fail, SW3 would wait MaxAge seconds before reacting (20 seconds is the default). SW3 would actually quickly choose its ports' STP roles, but then wait 15 seconds each in listening and learning states on interface Gi0/2, resulting in a 50-second convergence delay.

Table 1-8 summarizes spanning tree's various interface states for easier review.

Table 1-8. IEEE 802.1D Spanning-Tree States



State	Forwards Data Frames?	Learns MACs Based on Received Frames?	Transitory or Stable State?
Blocking	No	No	Stable
Listening	No	No	Transitory
Learning	No	Yes	Transitory
Forwarding	Yes	Yes	Stable
Disabled	No	No	Stable

Optional STP Features

STP has been around for more than 30 years, first being used even before the IEEE took over the development of Ethernet standards from Xerox and other vendors. The IEEE first standardized STP as IEEE 802.1D back in the 1980s. Cisco switches today still use STP. And other than changes to the default cost values, the description of STP in this chapter so far works like the original STP as created all those years ago.

Even with such an amazingly long life, STP has gone through several changes over these decades, some small, some large. For instance, Cisco added proprietary features to make improvements to STP. In some cases, the IEEE added these same improvements, or something like them, to later IEEE standards, whether as a revision of the 802.1D standard or as an additional standard. And STP has gone through one major revision that improves convergence, called the *Rapid Spanning Tree Protocol* (RSTP), as originally defined in IEEE 802.1w.

This final of three major sections of this chapter briefly discusses the basics of several of these optional features that go beyond the base 802.1D STP concepts, including EtherChannel, PortFast, and BPDU Guard.

EtherChannel

One of the best ways to lower STP's convergence time is to avoid convergence altogether. EtherChannel provides a way to prevent STP convergence from being needed when only a single port or cable failure occurs.

EtherChannel combines multiple parallel segments of equal speed (up to eight) between the same pair of switches, bundled into an EtherChannel. The switches treat the EtherChannel as a single interface with regard to STP. As a result, if one of the links fails, but at least one of the links is up, STP convergence does not have to occur. For example, Figure 1-10 shows the familiar three-switch network, but now with two Gigabit Ethernet connections between each pair of switches.

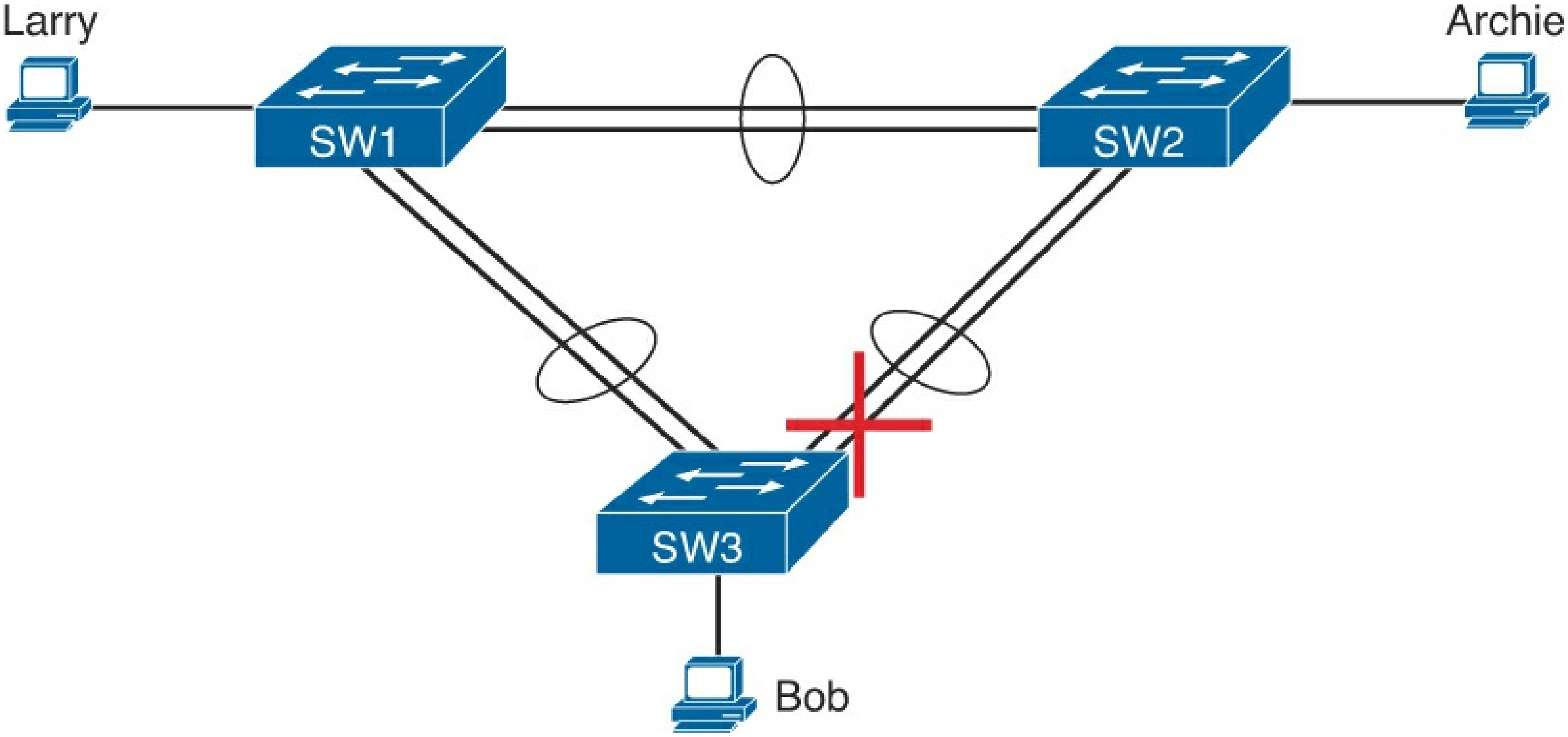


Figure 1-10. Two-Segment EtherChannels Between Switches

With each pair of Ethernet links configured as an EtherChannel, STP treats each EtherChannel as a single link. In other words, both links to the same switch must fail for a switch to need to cause STP convergence. Without EtherChannel, if you have multiple parallel links between two switches, STP blocks all the links except one. With EtherChannel, all the parallel links can be up and working at the same time, while reducing the number of times STP must converge, which in turn makes the network more available.

When a switch makes a forwarding decision to send a frame out an EtherChannel, the switch then has to take an extra step in logic: Out which physical interface does it send the frame? The switches have load-balancing logic that let it pick an interface for each frame, with a goal of spreading the traffic load across all active links in the channel. As a result, a LAN design that uses EtherChannels makes much better use of the available bandwidth between switches, while also reducing the number of times that STP must converge.

PortFast

PortFast allows a switch to immediately transition from blocking to forwarding, bypassing listening and learning states. However, the only ports on which you can safely enable PortFast are ports on which you know that no bridges, switches, or other STP-speaking devices are connected. Otherwise, using PortFast risks creating loops, the very thing that the listening and learning states are intended to avoid.

PortFast is most appropriate for connections to end-user devices. If you turn on PortFast on ports connected to end-user devices, when an end-user PC boots, the switch port can move to an STP forwarding state and forward traffic as soon as the PC NIC is active. Without PortFast, each port must wait while the switch confirms that the port is a DP, and then wait while the interface sits in the temporary listening and learning states before settling into the forwarding state.

BPDU Guard

STP opens up the LAN to several different types of possible security exposures. For example:

- An attacker could connect a switch to one of these ports, one with a low STP priority value, and become the root switch. The new STP topology could have worse performance than the desired topology.
- The attacker could plug into multiple ports, into multiple switches, become root, and actually forward much of the traffic in the LAN. Without the networking staff realizing it, the attacker could use a LAN analyzer to copy large numbers of data frames sent through the LAN.
- Users could innocently harm the LAN when they buy and connect an inexpensive consumer LAN switch (one that does not use STP). Such a switch, without any STP function, would not choose to block any ports and would likely cause a loop.

The Cisco BPDU Guard feature helps defeat these kinds of problems by disabling a port if any BPDUs are received on the port. So, this feature is particularly useful on ports that should be used only as an access port and never connected to another switch.

In addition, the BPDU Guard feature helps prevent problems with PortFast. PortFast should be enabled only on access ports that connect to user devices, not to other LAN switches. Using BPDU Guard on these same ports makes sense because if another switch connects to such a port, the local switch can disable the port before a loop is created.

Rapid STP (IEEE 802.1w)

As mentioned earlier in this chapter, the IEEE defines STP in the 802.1D IEEE standard. The IEEE has improved the 802.1D protocol with the definition of Rapid Spanning Tree Protocol (RSTP), as defined in standard 802.1w.

RSTP (802.1w) works just like STP (802.1D) in several ways:

- It elects the root switch using the same parameters and tiebreakers.
- It elects the root port on nonroot switches with the same rules.
- It elects designated ports on each LAN segment with the same rules.
- It places each port in either forwarding or blocking sate, although RSTP calls the blocking state the discarding state.

RSTP can be deployed alongside traditional 802.1D STP switches, with RSTP features working in switches that support it, and traditional 802.1D STP features working in the switches that support only STP.

With all these similarities, you might be wondering why the IEEE bothered to create RSTP in the first place. The overriding reason is convergence. STP takes a relatively long time to converge (50 seconds with the default settings). RSTP improves network convergence when topology changes occur, usually converging within a few seconds, or in poor conditions, in about 10 seconds.

In real life, most enterprise LANs use designs that require STP, and most of those prefer to use RSTP because of the better convergence. However, with the current exams, Cisco defers the deeper discussion of RSTP until the CCNP Switch exam and the CCNP certification. For those of you working with LAN switching for work, make sure to look further at 802.1w/RSTP and how to implement it in your switches.

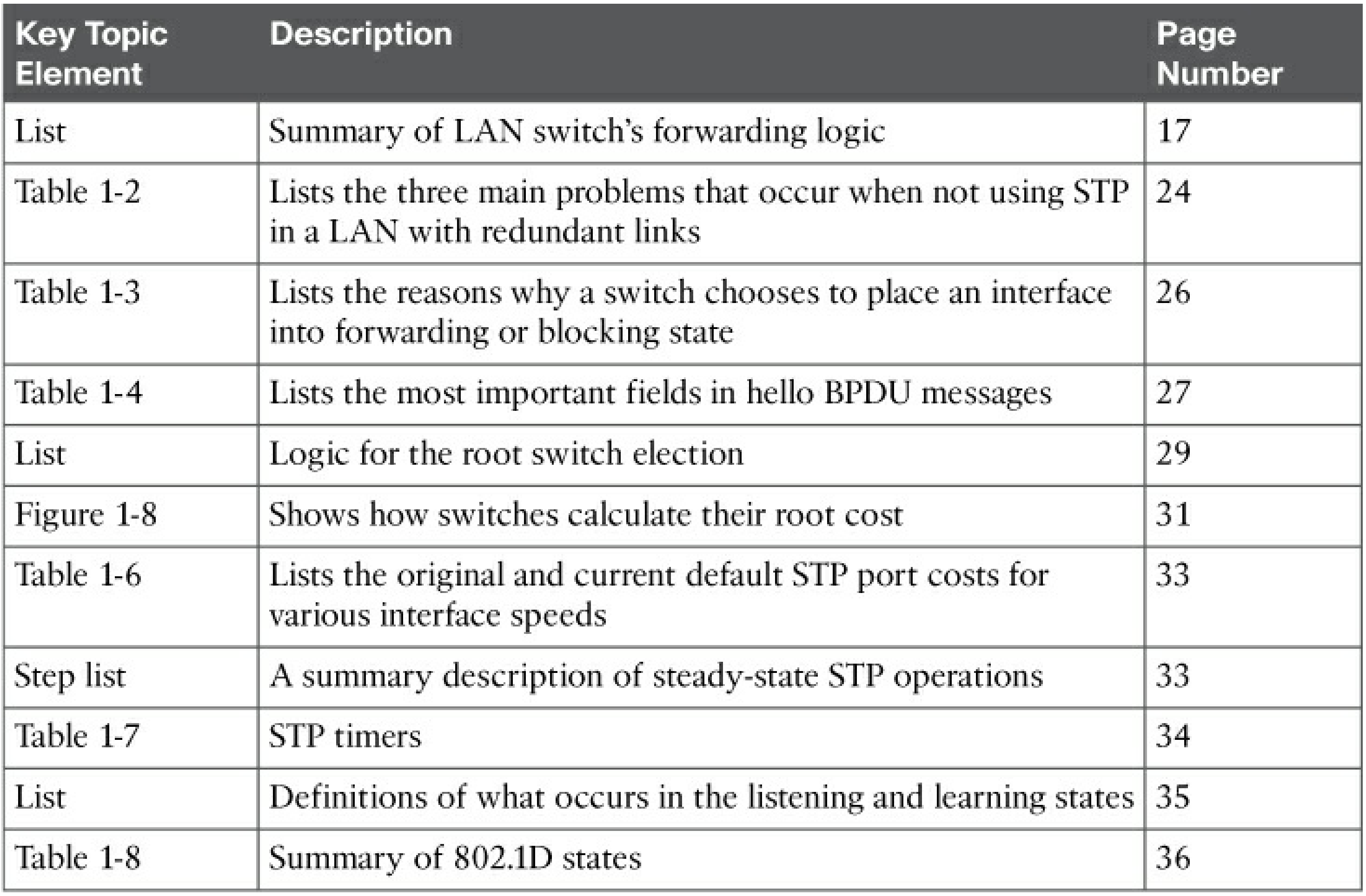
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 1-9 lists these key topics and where each is discussed.

Key Topic

Table 1-9. Key Topics for Chapter 1



Key Topic Element	Description	Page Number
List	Summary of LAN switch's forwarding logic	17
Table 1-2	Lists the three main problems that occur when not using STP in a LAN with redundant links	24
Table 1-3	Lists the reasons why a switch chooses to place an interface into forwarding or blocking state	26
Table 1-4	Lists the most important fields in hello BPDU messages	27
List	Logic for the root switch election	29
Figure 1-8	Shows how switches calculate their root cost	31
Table 1-6	Lists the original and current default STP port costs for various interface speeds	33
Step list	A summary description of steady-state STP operations	33
Table 1-7	STP timers	34
List	Definitions of what occurs in the listening and learning states	35
Table 1-8	Summary of 802.1D states	36

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix D, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix E, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22, "Final Review," directs you in how to use these terms for late-stage preparation for the exam.

blocking state
BPDU Guard
bridge ID
bridge protocol data unit (BPDU)
designated port
EtherChannel
forward delay
forwarding state
hello BPDU
IEEE 802.1D
learning state
listening state
MaxAge
PortFast
root port
root switch
root cost
Spanning Tree Protocol (STP)

Chapter 2. Spanning Tree Protocol Implementation

This chapter covers the following exam topics:

- **LAN Switching Technologies**
- Configure and verify PVSTP operation
    - Describe root bridge election
    - Spanning-tree mode
- **Troubleshooting**
- Troubleshoot and resolve spanning-tree operation issues
    - Root switch
    - Priority
    - Mode is correct
    - Port states
- Troubleshoot EtherChannel problems

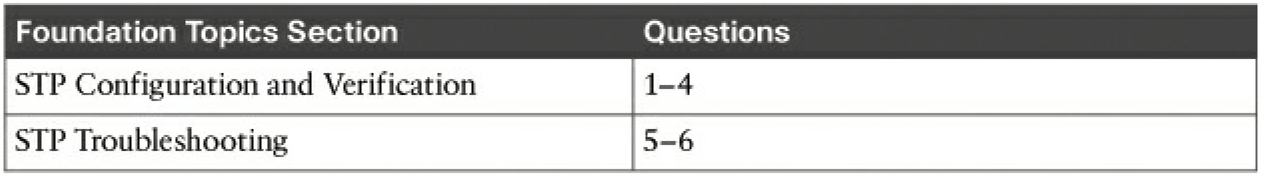
Cisco LAN switches enable Spanning Tree Protocol (STP) by default on all interfaces in every VLAN. However, network engineers who work with medium-size to large-size Ethernet LANs usually want to configure at least some STP settings, with the goal of influencing the choices made by STP. For instance, a network engineer configures so that, when all switches and links work, the engineer knows which switch is the root and which ports block. The configuration can also be set so that when links or switches fail, the engineer can predict the STP topology in those cases, as well.

This chapter discusses the configuration options for STP, assuming the switches use 802.1D STP. The first major section weaves a story of how to change different settings, per VLAN, with the **show** commands that reveal the current STP status affected by each configuration command. The second major section of this chapter looks at how to troubleshoot STP, which includes a deeper examination of the STP rules discussed in Chapter 1, "Spanning Tree Protocol Concepts," plus more discussion of various switch **show** commands.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 2-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
STP Configuration and Verification	1–4
STP Troubleshooting	5–6

1. On a 2960 switch, which of the following commands change the value of the bridge ID? (Choose two answers.)
    - **a. spanning-tree bridge-id** *value*
    - **b. spanning-tree vlan** *vlan-number* **root** {**primary** | **secondary**}
    - **c. spanning-tree vlan** *vlan-number* **priority** *value*
    - **d. set spanning-tree priority** *value*
2. Examine the following extract from the **show spanning-tree** command on a Cisco switch:

Click here to view code image

```
Bridge ID Priority 32771 (priority 32768 sys-id-ext 3)
Address 0019.e86a.6f80
```

Which of the following answers is true about the switch on which this command output was gathered?

- **a.** The information is about the STP instance for VLAN 1.
- **b.** The information is about the STP instance for VLAN 3.
- **c.** The command output confirms that this switch cannot possibly be the root switch.
- **d.** The command output confirms that this switch is currently the root switch.

3. A switch's G0/1 interface, a trunk that supports VLANs 1-10, has autonegotiated a speed of 100 Mbps. The switch currently has all default settings for STP. Which of the following actions results in the switch using a STP cost of 19 for that interface in VLAN 3? (Choose two answers.)
    - **a. spanning-tree cost 19**
    - **b. spanning-tree port-cost 19**

   - **c. spanning-tree vlan 3 port-cost 19**
   - **d.** Adding no configuration

4. An engineer configures a switch to put interfaces G0/1 and G0/2 into the same EtherChannel. Which of the following terms is used in the configuration commands?
   - **a. EtherChannel**
   - **b. PortChannel**
   - **c. Ethernet-Channel**
   - **d. Channel-group**

5. Switch SW3 is receiving only two hello BPDUs, both from the same root switch, received on the two interfaces listed as follows:

Click here to view code image

```
SW3# show interfaces status
Port Name Status Vlan Duplex Speed Type
Fa0/13 connected 1 a-half a-100 10/100BaseTX
Gi0/1 connected 1 a-full a-1000 1000BaseTX
```

SW3 has no STP-related configuration commands. The hello received on Fa0/13 lists root cost 10, and the hello received on Gi0/1 lists root cost 20. Which of the following is true about STP on SW3?
   - **a.** SW3 will choose Fa0/13 as its root port.
   - **b.** SW3 will choose Gi0/1 as its root port.
   - **c.** SW3's Fa0/13 will become a designated port.
   - **d.** SW3's Gi0/1 will become a designated port.

6. Which of the following commands lists a nonroot switch's root cost? (Choose two answers.)
   - **a. show spanning-tree root**
   - **b. show spanning-tree root-cost**
   - **c. show spanning-tree bridge**
   - **d. show spanning-tree**

Answers to the "Do I Know This Already?" quiz:

1 B and C **2** B **3** A and D **4** D **5** B **6** A and D

Foundation Topics

STP Configuration and Verification

Cisco switches usually use STP (IEEE 802.1D) by default. You can buy some Cisco switches and connect them with Ethernet cables in a redundant topology, and STP will ensure that frames do not loop. And you never even have to think about changing any settings!

Although STP works without any configuration, most medium-size to large-size campus LANs benefit from some STP configuration. With all defaults, the switches choose the root based on the lowest burned-in MAC address on the switches because they all default to use the same STP priority. As a better option, configure the switches so that the root is predictable.

For instance, Figure 2-1 shows a typical LAN design model, with two distribution layer switches (D1 and D2). The design may have dozens of access layer switches that connect to end users; the figure shows just three access switches (A1, A2, and A3). For a variety of reasons, most network engineers make the distribution layer switches be the root. For instance, the configuration could make D1 be the root by having a lower priority, with D2 configured with the next lower priority, so it becomes root if D1 fails.

Key Topic

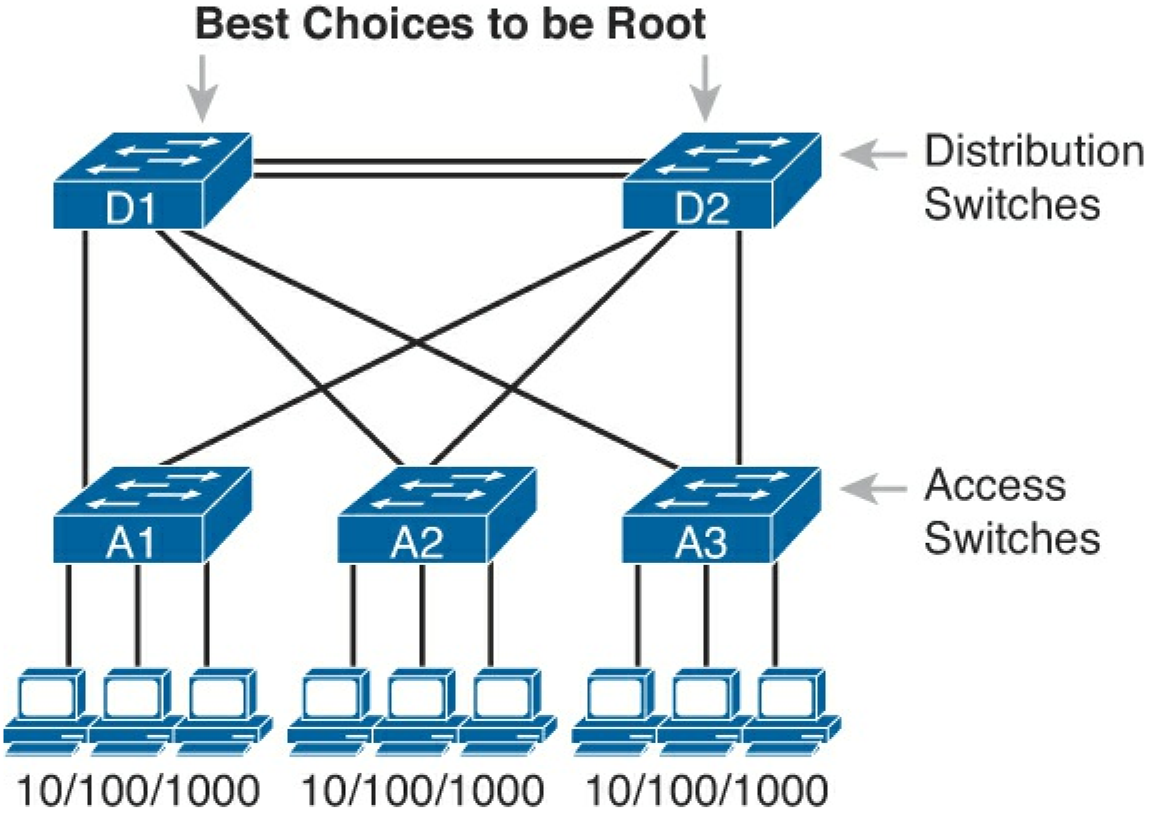


Figure 2-1. Typical Configuration Choice: Making Distribution Switch Be Root

This first section of the chapter examines a variety of topics that somehow relate to STP configuration. It begins with a look at STP configuration options, as a way to link the concepts of Chapter 1 to the configuration choices in this chapter. Following that, this section introduces some **show** commands for the purpose of verifying the default STP settings before changing any configuration. At that point, this section shows examples of how to configure core STP features and some of the optional STP features.

Setting the STP Mode

Chapter 1 described how 802.1D STP works in one VLAN. Now that this chapter turns our attention to STP configuration in Cisco switches, one of the first questions is this: Which kind of STP do you intend to use in a LAN? And to answer that question, you need to know a little more background.

The IEEE first standardized STP as the IEEE 802.1D standard, first published back in 1990. To put some perspective on that date, Cisco sold no LAN switches at the time, and virtual LANs did not exist yet. As a result, the STP protocol has gone through several significant changes with the introduction of switches, VLANs, and other improvements in LAN technology.

Today, Cisco LAN switches allow you to use one of three STP modes that reflect that history. For instance, the one mode discussed in this chapter, Per-VLAN Spanning Tree Plus (PVST+, or sometimes PVSTP), is a Cisco-proprietary improvement of 802.1D STP. The *per-VLAN* part of the name gives away the main feature: PVST+ creates a different STP topology per VLAN, whereas 802.1D actually did not. PVST+ also introduced PortFast.

Over time, the IEEE improved STP beyond the 802.1D standard with the Rapid STP (802.1w) protocol. Then Cisco took that standard and made another proprietary improvement, creating another mode in Cisco switches: Rapid PVST+, or simply RPVST+. It has all the improvements of the newer IEEE standard per-VLAN.

This book focuses on one mode only: PVST+. Cisco switches generally default to using PVST+, but to set a switch to use this mode, use the **spanning-tree mode pvst** global command. Alternatively, switches allow RPVST+ with the **spanning-tree mode rapid-pvst** command, and Multiple Spanning Tree (MST) with the **spanning-tree mode mst** command.

All the examples in this chapter use 2960 switches, with PVST+ as the default STP mode.

Connecting STP Concepts to STP Configuration Options

If you think back to the details of STP operation in Chapter 1, STP uses two types of numbers for most of its decisions: the BID and STP port costs. Focusing on those two types of numbers, consider this summary of what STP does behind the scenes:

- Use the BID to elect the root switch, electing the switch with the numerically lowest BID.
- Use the total STP cost in each path to the root, when each nonroot switch chooses its own root port (RP).
- Use each switch’s root cost, which is in turn based on STP port costs, when switches decide which switch port becomes the designated port (DP) on each LAN segment.

Unsurprisingly, Cisco switches let you configure part of a switch’s BID and the STP port cost, which in turn influences the choices each switch makes with STP.

Per-VLAN Configuration Settings

Beyond supporting the configuration of the BID and STP port costs, Cisco switches support configuring both settings per VLAN. By default, Cisco switches use IEEE 802.1D, not RSTP (802.1w), with a Cisco-proprietary feature called Per-VLAN Spanning Tree Plus (PVST+). PVST+ (often abbreviated as simply PVST today) creates a different instance of STP for each VLAN. So, before looking at the tunable STP parameters, you need to have a basic understanding of PVST+, because the configuration settings can differ for each instance of STP.

PVST+ gives engineers a load-balancing tool with STP. By changing some STP configuration parameters differently for different VLANs, the engineer could cause switches to pick different RPs and DPs in different VLANs. As a result, some traffic in some VLANs can be forwarded over one trunk, and traffic for other VLANs can be forwarded over a different trunk.

Figure 2-2 shows the basic idea, with SW3 forwarding odd-numbered VLAN traffic over the left trunk (Gi0/1) and even-numbered VLANs over the right trunk (Gi0/2).

Key Topic

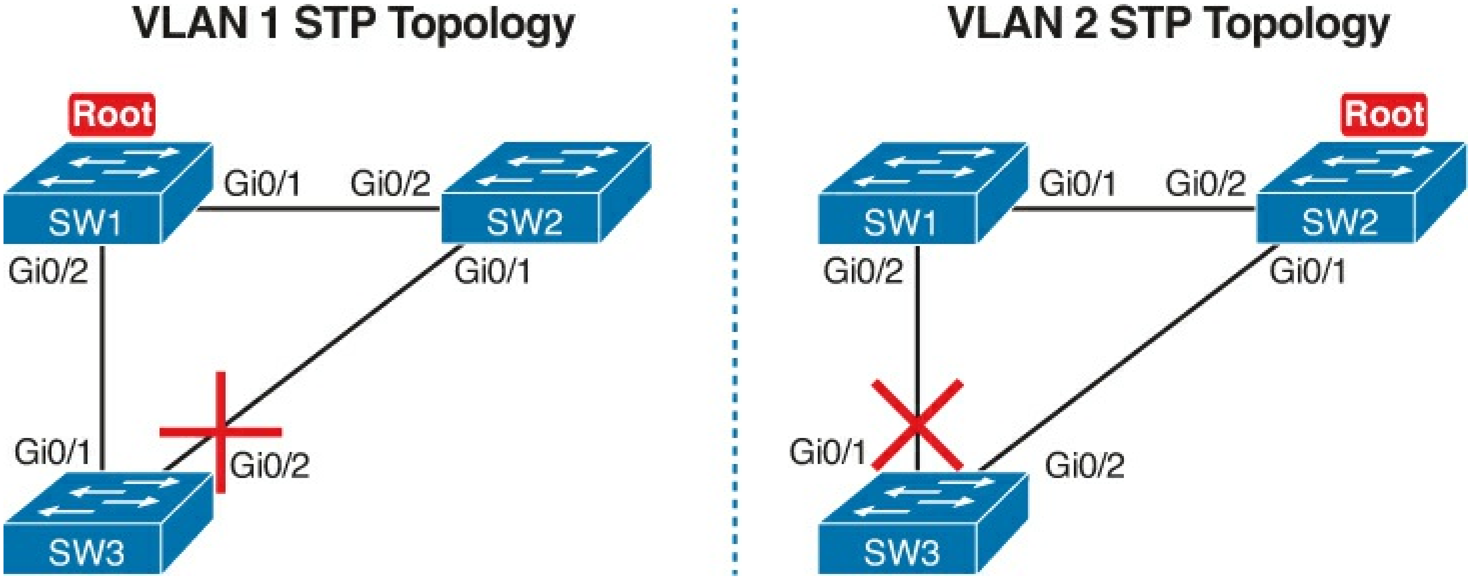

VLAN 1 STP Topology
Root
SW1
Gi0/1
Gi0/2
SW2
Gi0/2
Gi0/1
Gi0/1
Gi0/2
SW3
VLAN 2 STP Topology
Root
SW1
Gi0/1
Gi0/2
SW2
Gi0/2
Gi0/1
Gi0/1
Gi0/2
SW3

Figure 2-2. Load Balancing with PVST+

The next few pages look specifically at how to change the BID and STP port cost settings, per VLAN, when using the default PVST+ mode.

The Bridge ID and System ID Extension

Originally, a switch's BID was formed by combining the switch's 2-byte priority and its 6-byte MAC address. Later, the IEEE changed the rules, splitting the original priority field into two separate fields, as shown in Figure 2-3: a 4-bit priority field and a 12-bit subfield called the *system ID extension* (which represents the VLAN ID).

Key Topic

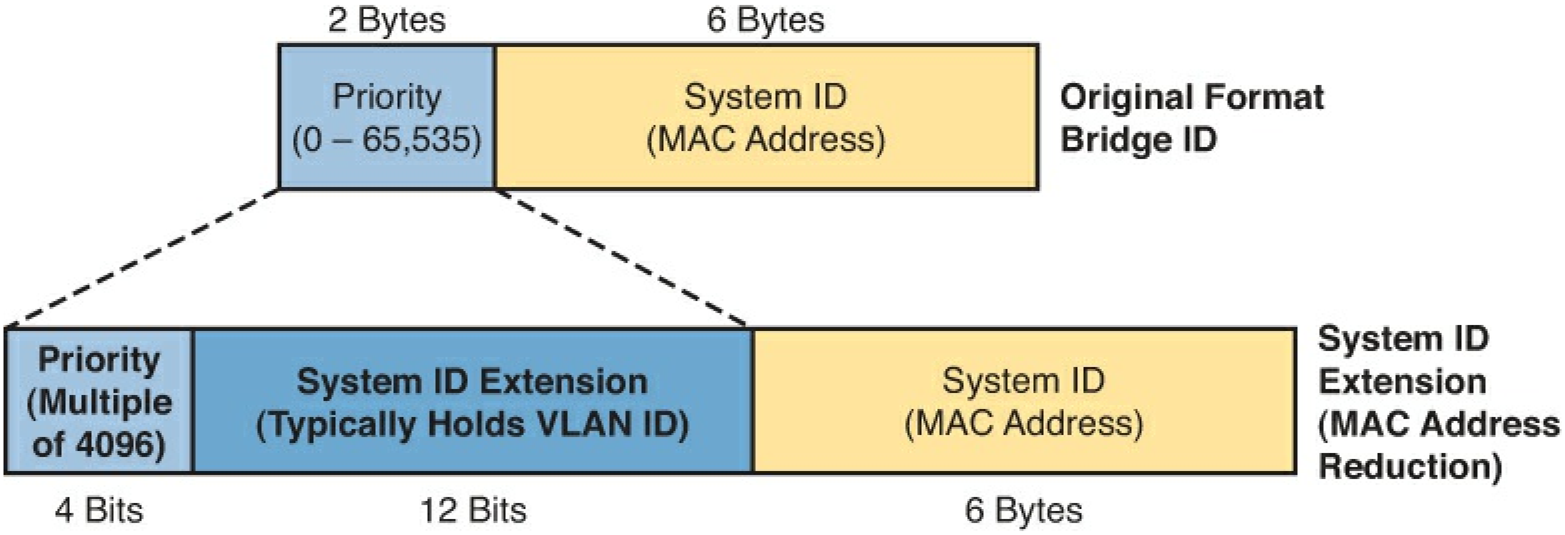

2 Bytes
6 Bytes
Priority (0 – 65,535)
System ID (MAC Address)
Original Format Bridge ID
Priority (Multiple of 4096)
System ID Extension (Typically Holds VLAN ID)
System ID (MAC Address)
System ID Extension (MAC Address Reduction)
4 Bits
12 Bits
6 Bytes

Figure 2-3. STP System ID Extension

Cisco switches let you configure the BID, but only the priority part. The switch fills in its universal (burned-in) MAC address as the system ID. It also plugs in the VLAN ID of a VLAN in the 12-bit system ID extension field. The only part configurable by the network engineer is the 4-bit priority field.

Configuring the number to put in the priority field, however, is one of the strangest things to configure on a Cisco router or switch. As shown at the top of Figure 1-3, the priority field was originally a 16-bit number, which represented a decimal number from 0 to 65,535. Because of that history, the current configuration command (**spanning-tree vlan** *vlan-id* **priority** *x*) requires a decimal number between 0 and 65,535. And not just any number in that range, either: It must be a multiple of 4096: 0, 4096, 8192, 12288, and so on, up through 61,440.

The switch still sets the first 4 bits of the BID based on the configured value. As it turns out, of the 16 allowed multiples of 4096, from 0 through 61,440, each has a different binary value in their first 4 bits: 0000, 0001, 0010, and so on, up through 1111. The switch sets the true 4-bit priority based on the first 4 bits of the configured value.

Although the history and configuration might make the BID priority idea seem a bit convoluted, having an extra 12-bit field in the BID works well in practice because it can be used to identify the VLAN ID. VLAN IDs range from 1 to 4094, requiring 12 bits. Cisco switches place the VLAN ID into the System ID Extension field, so each switch has a unique BID per VLAN.

For example, a switch configured with VLANs 1 through 4, with a default base priority of 32,768, has a default STP priority of 32,769 in VLAN 1, 32,770 in VLAN 2, 32,771 in VLAN 3, and so on. So, you can view the 16-bit priority as a base priority (as configured on the **spanning-tree vlan** *vlan-id* **priority** *x* command) plus the VLAN ID.

Per-VLAN Port Costs

Each switch interface defaults its per-VLAN STP cost based on the IEEE recommendations listed in Table 1-6 in Chapter 1. On interfaces that support multiple speeds, Cisco switches base the cost on the current actual speed. So, if an interface negotiates to use a lower speed, the default STP cost reflects that lower speed. If the interface negotiates to use a different speed, the switch dynamically changes the STP port cost as well.

Alternatively, you can configure a switch's STP port cost with the **spanning-tree** [**vlan** *vlan-id*] **cost** *cost* interface subcommand. You see this command most often on trunks because setting the cost on trunks has an impact on the switch's root cost, whereas setting STP costs on access ports does not.

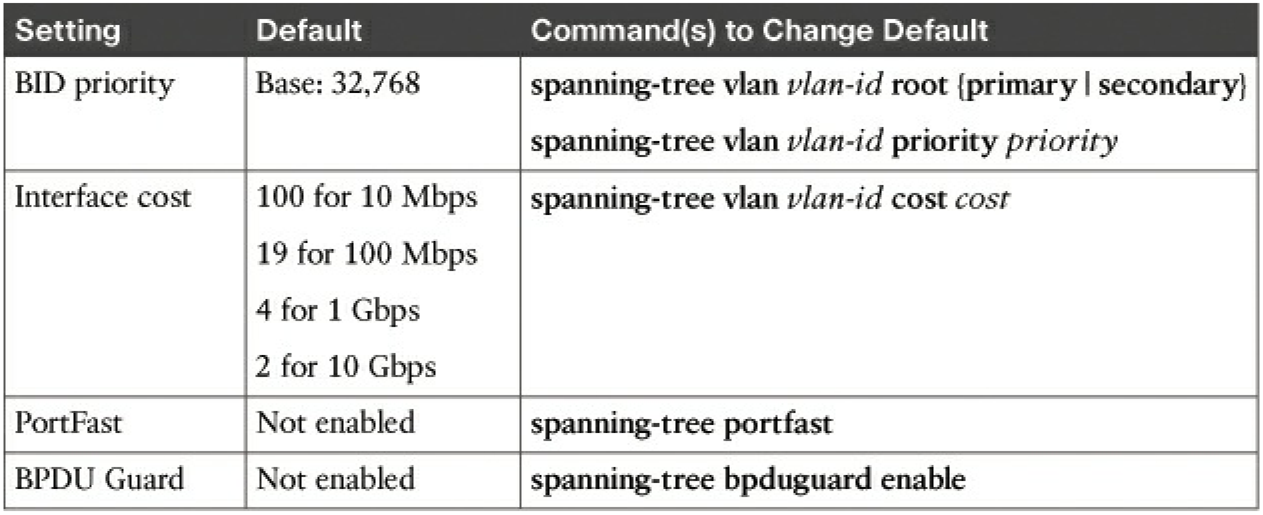
For the command itself, it can include the VLAN ID, or not. The command only needs a **vlan** parameter on trunk ports to set the cost per VLAN. On a trunk, if the command omits the VLAN parameter, it sets the STP cost for all VLANs whose cost is not set by a **spanning-tree vlan** *x* **cost** command for that VLAN.

STP Configuration Option Summary

Table 2-2 summarizes the default settings for both the BID and the port costs and lists the optional configuration commands covered in this chapter.

Key Topic

Table 2-2. STP Defaults and Configuration Options



Setting	Default	Command(s) to Change Default
BID priority	Base: 32,768	**spanning-tree vlan** *vlan-id* **root {primary | secondary}** **spanning-tree vlan** *vlan-id* **priority** *priority*
Interface cost	100 for 10 Mbps 19 for 100 Mbps 4 for 1 Gbps 2 for 10 Gbps	**spanning-tree vlan** *vlan-id* **cost** *cost*
PortFast	Not enabled	**spanning-tree portfast**
BPDU Guard	Not enabled	**spanning-tree bpduguard enable**

Next, the configuration section shows how to examine the operation of STP in a simple network, along with how to change these optional settings.

Verifying STP Operation

Before taking a look at how to change the configuration, first consider a few STP verification commands. Looking at these commands first will help reinforce the default STP settings. In particular, the examples in this section use the network shown in Figure 2-4.

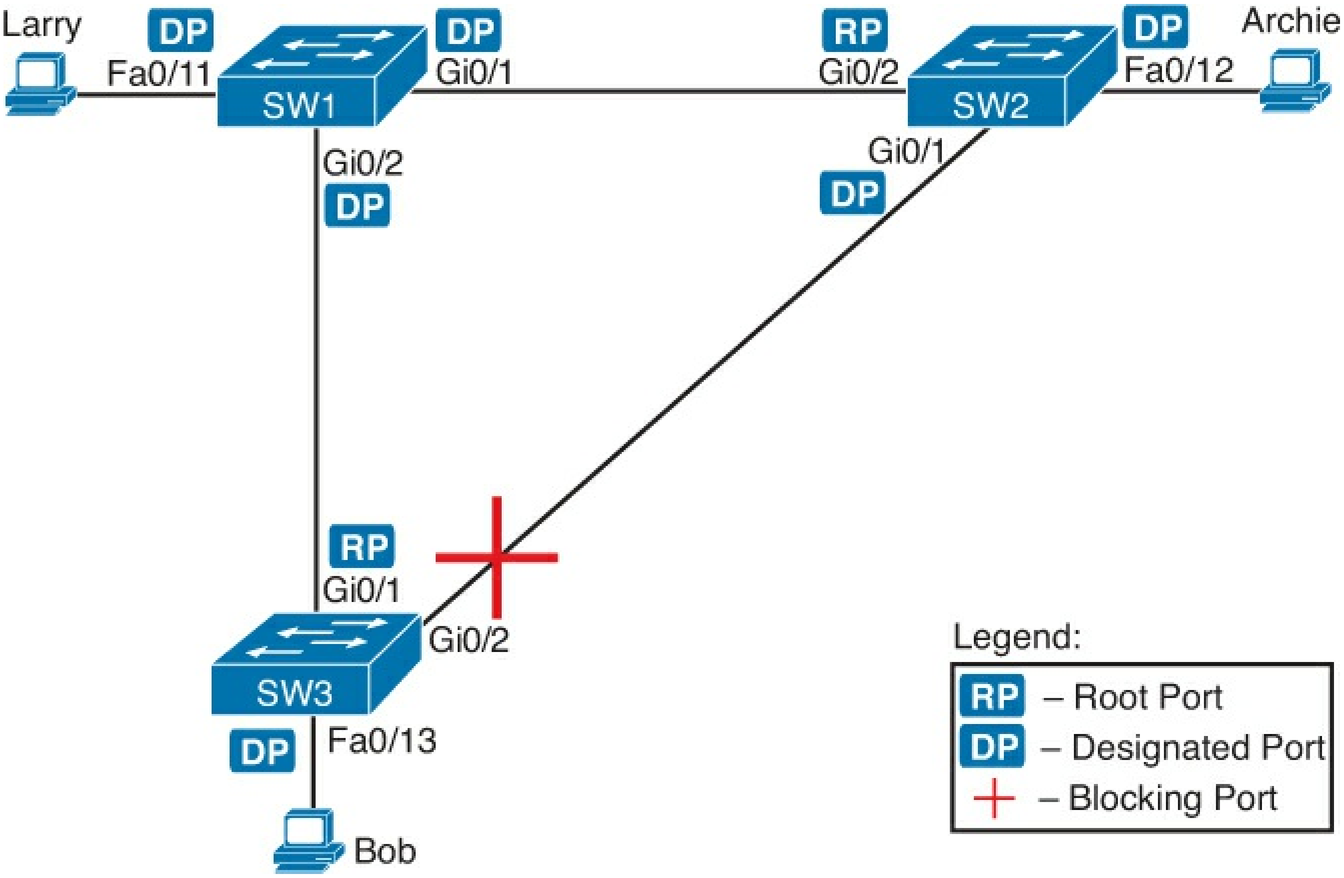

Larry
DP
Fa0/11
SW1
DP
Gi0/1
RP
Gi0/2
SW2
DP
Fa0/12
Archie
Gi0/2
DP
Gi0/1
DP
RP
Gi0/1
Gi0/2
SW3
DP
Fa0/13
Bob
Legend:
RP – Root Port
DP – Designated Port
– Blocking Port

Figure 2-4. Sample LAN for STP Configuration and Verification Examples

Example 2-1 begins the discussion with a useful command for STP: the **show spanning-tree vlan 10** command. This command identifies the root switch and lists settings on the local switch. Example 2-1 lists the output of this command on both SW1 and SW2, as explained following the example.

Example 2-1. STP Status with Default STP Parameters on SW1 and SW2

Click here to view code image

```
SW1# show spanning-tree vlan 10

VLAN0010
Spanning tree enabled protocol ieee
Root ID Priority 32778
Address 1833.9d7b.0e80
This bridge is the root
Hello Time 2 sec Max Age 20 sec Forward Delay 15 sec

Bridge ID Priority 32778 (priority 32768 sys-id-ext 10)
Address 1833.9d7b.0e80
Hello Time 2 sec Max Age 20 sec Forward Delay 15 sec
Aging Time 300 sec

Interface Role Sts Cost Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------------
Fa0/11 Desg FWD 19 128.11 P2p Edge
Gi0/1 Desg FWD 4 128.25 P2p
Gi0/2 Desg FWD 4 128.26 P2p
```

```
SW2# show spanning-tree vlan 10

VLAN0010
Spanning tree enabled protocol ieee
Root ID Priority 32778
Address 1833.9d7b.0e80
Cost 4
Port 26 (GigabitEthernet0/2)
Hello Time 2 sec Max Age 20 sec Forward Delay 15 sec
```

```
Bridge ID Priority 32778 (priority 32768 sys-id-ext 10)
Address 1833.9d7b.1380
Hello Time 2 sec Max Age 20 sec Forward Delay 15 sec
Aging Time 300 sec

Interface Role Sts Cost Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------------
Fa0/12 Desg FWD 19 128.12 P2p
Gi0/1 Desg FWD 4 128.25 P2p
Gi0/2 Root FWD 4 128.26 P2p
```

Example 2-1 begins with the output of the **show spanning-tree vlan 10** command on SW1. This command first lists three major groups of messages: one group of messages about the root switch, followed by another group about the local switch, and ending with interface role and status information. In this case, SW1 lists its own BID as the root, with even a specific statement that "This bridge is the root," confirming that SW1 is now the root of the VLAN 10 STP topology.

Next, compare the highlighted lines of the same command on SW2 in the lower half of the example. SW2 lists SW1's BID details as the root; in other words, SW2 agrees that SW1 has won the root election. SW2 does not list the phrase "This bridge is the root." SW1 then lists its own (different) BID details in the lines after the details about the root's BID.

The output also confirms a few default values. First, each switch lists the priority part of the BID as a separate number: 32778. This value comes from the default priority of 32768, plus VLAN 10, for a total of 32778. The output also shows the interface cost for some Fast Ethernet and Gigabit Ethernet interfaces, defaulting to 19 and 4, respectively.

Finally, the bottom of the output from the **show spanning-tree** command lists each interface in the VLAN, including trunks, with the STP port role and port state listed. For instance, on switch SW1, the output lists three interfaces, with a role of Desg for designated port (DP) and a state of FWD for forwarding. SW2 lists three interfaces, two DPs, and one root port, so all three are in an FWD or forwarding state.

Example 2-1 shows a lot of good STP information, but two other commands, shown in Example 2-2, work better for listing BID information in a shorter form. The first, **show spanning-tree root**, lists the root's BID for each VLAN. This command also lists other details, like the local switch's root cost and root port. The other command, **show spanning-tree vlan 10 bridge**, breaks out the BID into its component parts. In this example, it shows SW2's priority as the default of 32768, the VLAN ID of 10, and the MAC address.

Example 2-2. Listing Root Switch and Local Switch BIDs on Switch SW2

Click here to view code image

```
SW2# show spanning-tree root

Root Hello Max Fwd
Vlan Root ID Cost Time Age Dly Root Port
---------------- -------------------- --------- ----- --- --- ------------
VLAN0001 32769 1833.9d5d.c900 23 2 20 15 Gi0/1
VLAN0010 32778 1833.9d7b.0e80 4 2 20 15 Gi0/2
VLAN0020 32788 1833.9d7b.0e80 4 2 20 15 Gi0/2
VLAN0030 32798 1833.9d7b.0e80 4 2 20 15 Gi0/2
VLAN0040 32808 1833.9d7b.0e80 4 2 20 15 Gi0/2

SW2# show spanning-tree vlan 10 bridge

Hello Max Fwd
Vlan Bridge ID Time Age Dly Protocol
---------------- --------------------------------- ----- --- --- --------
VLAN0010 32778 (32768, 10) 1833.9d7b.1380 2 20 15 ieee
```

Note that both the commands in Example 2-2 have a VLAN option: **show spanning-tree** [**vlan** *x*] **root** and **show spanning-tree** [**vlan** *x*] **bridge**. Without the VLAN listed, each command lists one line per VLAN; with the VLAN, the output lists the same information, but just for that one VLAN.

Configuring STP Port Costs

Changing the STP port costs requires a simple interface subcommand: **spanning-tree** [**vlan** *x*] **cost** *x*. To show how it works, consider the following example, which changes what happens in the network shown in Figure 2-4.

Back in Figure 2-4, with default settings, SW1 became root, and SW3 blocked on its G0/2 interface. A brief scan of the figure, based on the default STP cost of 4 for Gigabit interfaces, shows that SW3 should have found a cost 4 path and a cost 8 path to reach the root, as shown in Figure 2-5.

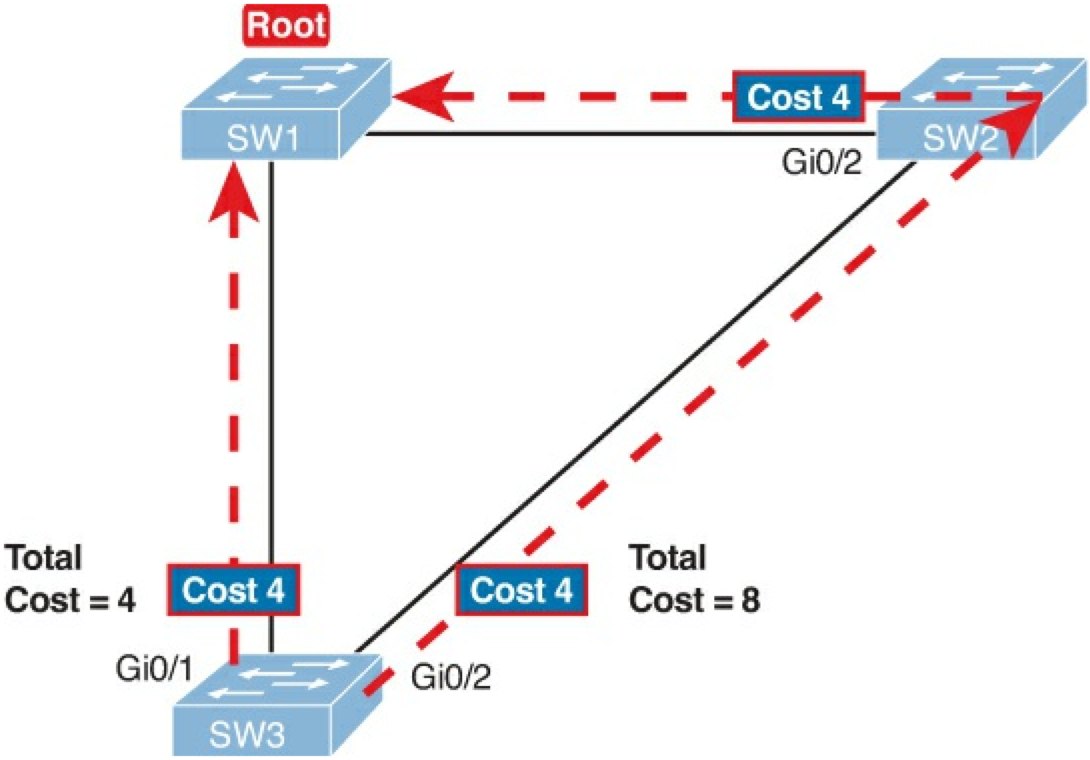


Figure 2-5. Analysis of SW3's Current Root Cost of 4 with Defaults

To show the effects of changing the port cost, the next example shows a change to SW3's configuration, setting its G0/1 port cost higher so that the better path to the root goes out SW3's G0/2 port instead. Example 2-3 also shows several other interesting effects.

Example 2-3. Manipulating STP Port Cost and Watching the Transition to Forwarding State

Click here to view code image

```
SW3# debug spanning-tree events
Spanning Tree event debugging is on
SW3# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
SW3(config)# interface gigabitethernet0/1
SW3(config-if)# spanning-tree vlan 10 cost 30

SW3(config-if)# ^Z
SW3#
*Mar 11 06:28:00.860: STP: VLAN0010 new root port Gi0/2, cost 8
*Mar 11 06:28:00.860: STP: VLAN0010 Gi0/2 -> listening
*Mar 11 06:28:00.860: STP: VLAN0010 sent Topology Change Notice on Gi0/2
*Mar 11 06:28:00.860: STP[10]: Generating TC trap for port GigabitEthernet0/1
*Mar 11 06:28:00.860: STP: VLAN0010 Gi0/1 -> blocking
*Mar 11 06:28:15.867: STP: VLAN0010 Gi0/2 -> learning
*Mar 11 06:28:30.874: STP[10]: Generating TC trap for port GigabitEthernet0/2
*Mar 11 06:28:30.874: STP: VLAN0010 sent Topology Change Notice on Gi0/2
*Mar 11 06:28:30.874: STP: VLAN0010 Gi0/2 -> forwarding
```

This example starts with the **debug spanning-tree events** command on SW1. This command tells the switch to issue debug log messages whenever STP performs changes to an interface's role or state. These messages show up in the example as a result of the configuration.

Next, the example shows the configuration to change SW3's port cost, in VLAN 10, to 30, with the **spanning-tree vlan 10 cost 30** interface subcommand. Based on the figure, the root cost through SW3's G0/1 will now be 30 instead of 4. As a result, SW3's best cost to reach the root is cost 8, with SW3's G0/2 as its root port.

The debug messages tell us what STP on SW3 is thinking behind the scenes, with timestamps. Note that the first five debug messages, displayed immediately after the user exited configuration mode in this case, all happen at the same time (down to the same millisecond). Notably, G0/1, which had been forwarding, immediately moves to a blocking state. Interface G0/2, which had been blocking, does not go to a forwarding state, instead moving to a listening state (at least, according to this message).

Now look for the debug message that lists G0/2 transitioning to learning state, and then the next one that shows it finally reaching forwarding state. How long between the messages? In each case, the message's timestamps show that 15 seconds passed. In this experiment, the switches used a default setting of MaxAge (15 seconds). So, these debug messages confirm the steps that STP takes to transition an interface from blocking to forwarding state.

If you did not happen to enable a debug when configuring the cost, using **show** commands later can confirm the same choice by SW3, to now use its G0/2 port as its RP. Example 2-4 shows the new STP port cost setting on SW3, along with the new root port and root cost, using the **show spanning-tree vlan 10** command. Note that G0/2 is now listed as the root port. The top of the output lists SW3's root cost as 8, matching the analysis shown in Figure 2-5.

Example 2-4. New STP Status and Settings on SW3

Click here to view code image

```
SW3# show spanning-tree vlan 10

VLAN0010
Spanning tree enabled protocol ieee
Root ID Priority 32778
Address 1833.9d7b.0e80
Cost 8
Port 26 (GigabitEthernet0/2)
Hello Time 2 sec Max Age 20 sec Forward Delay 15 sec

Bridge ID Priority 32778 (priority 32768 sys-id-ext 10)
Address f47f.35cb.d780
Hello Time 2 sec Max Age 20 sec Forward Delay 15 sec
Aging Time 300 sec

Interface Role Sts Cost Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------------
Fa0/23 Desg FWD 19 128.23 P2p
Gi0/1 Altn BLK 30 128.25 P2p
Gi0/2 Root FWD 4 128.26 P2p
```

Configuring Priority to Influence the Root Election

The other big STP configuration option is to influence the root election by changing the priority of a switch. The priority can be set explicitly with the **spanning-tree vlan** *vlan-id* **priority** *value* global configuration command, which sets the base priority of the switch. (This is the command that requires a parameter of a multiple of 4096.)

However, Cisco gives us a better configuration option than configuring a specific priority value. In most designs, the network engineers pick two switches to be root: one to be root if all switches are up, and another to take over if the first switch fails. Switch IOS supports this idea with the **spanning-tree vlan** *vlan-id* **root primary** and **spanning-tree vlan** *vlan-id* **root secondary** commands

The **spanning-tree vlan** *vlan-id* **root primary** command tells the switch to set its priority low enough to become root right now. The switch looks at the current root in that VLAN, and at the root's priority. Then the local switch chooses a priority value that causes the local switch to take over as root.

Remembering that Cisco switches use a default base priority of 32,768, this command chooses the base priority as follows:

Key Topic

- If the current root has a base priority higher than 24,576, *the local switch uses a base priority of 24,576.*
- If the current root's base priority is 24,576 or lower, the local switch sets its base priority to the highest multiple of 4096 that still results in the local switch becoming root.

For the switch intended to take over as the root if the first switch fails, use the **spanning-tree vlan** *vlan-id* **root secondary** command. This command is much like the **spanning-tree vlan** *vlan-id* **root primary** command, but with a priority value worse than the primary switch but better than all the other switches. This command sets the switch's base priority to 28,672 regardless of the current root's current priority value.

For example, in Figures 2-4 and 2-5, SW1 was the root switch, and as shown in various commands, all three switches defaulted to use a base priority of 32,768. Example 2-5 shows a configuration that makes SW2 the primary root, and SW1 the secondary, just to show the role move from one to the other. These commands result in SW2 having a base priority of 24,576, and SW1 having a base priority of 28,672.

Example 2-5. Making SW2 Become Root Primary, and SW1 Root Secondary

Click here to view code image

```
! First, on SW2:
SW2# configure terminal
```

```
Enter configuration commands, one per line. End with CNTL/Z.
SW2(config)# spanning-tree vlan 10 root primary
SW2(config)# ^Z
```

```
! Next, SW1 is configured to back-up SW1
SW1# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
SW1(config)# spanning-tree vlan 10 root secondary

SW1(config)# ^Z
SW1#

! The next command shows the local switch's BID (SW1)
SW1# show spanning-tree vlan 10 bridge

Hello Max Fwd
Vlan Bridge ID Time Age Dly Protocol
---------------- --------------------------------- ----- --- --- --------
VLAN0010 28682 (28672, 10) 1833.9d7b.0e80 2 20 15 ieee

! The next command shows the root's BID (SW2)
SW1# show spanning-tree vlan 10 root

Root Hello Max Fwd
Vlan Root ID Cost Time Age Dly Root Port
---------------- -------------------- --------- ----- --- --- ------------
VLAN0010 24586 1833.9d7b.1380 4 2 20 15 Gi0/1
```

The two **show** commands in the output clearly point out the resulting priority values on each switch. First, the **show spanning-tree bridge** command lists the local switch's BID information, while the **show spanning-tree root** command lists the root's BID, plus the local switch's root cost and root port (assuming it is not the root switch). So, SW1 lists its own BID, with priority 28,682 (base 28,672, with VLAN 10) with the **show spanning-tree bridge** command. Still on SW1, the output lists the root's priority as 24,586 in VLAN 10, implied as base 24,576 plus 10 for VLAN 10, with the **show spanning-tree root** command.

Note that alternatively you could have configured the priority settings specifically. SW1 could have used the **spanning-tree vlan 10 priority 28672** command, with SW2 using the **spanning-tree vlan 10 priority 24576** command. In this particular case, both options would result in the same STP operation.

Configuring PortFast and BPDU Guard

You can easily configure the PortFast and BPDU Guard features on any interface, but with two difference configuration options. One option works best when you only want to enable these features on a few ports, and the other works best when you want to enable these features on most every access port.

First, to enable the features on just one port at a time, use the **spanning-tree portfast** and the **spanning-tree bpduguard enable** interface subcommands. Example 2-6 shows an example of the process, with SW3's F0/4 interface enabling both features. (Also, note the long warning message IOS lists when enabling PortFast; using portfast on a port connected to other switches can indeed cause serious problems.)

Example 2-6. Enabling PortFast and BPDU Guard on One Interface

Click here to view code image

```
SW3# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
SW3(config)# interface fastEthernet 0/4
SW3(config-if)# spanning-tree portfast
%Warning: portfast should only be enabled on ports connected to a single
host. Connecting hubs, concentrators, switches, bridges, etc... to this
interface when portfast is enabled, can cause temporary bridging loops.
Use with CAUTION

%Portfast has been configured on FastEthernet0/4 but will only
have effect when the interface is in a non-trunking mode.

SW3(config-if)# spanning-tree bpduguard ?
disable Disable BPDU guard for this interface
enable Enable BPDU guard for this interface
```

```
SW3(config-if)# spanning-tree bpduguard enable
SW3(config-if)# ^Z
SW3#
*Mar 1 07:53:47.808: %SYS-5-CONFIG_I: Configured from console by console
SW3# show running-config interface f0/4
Building configuration...

Current configuration : 138 bytes
!
interface FastEthernet0/4
switchport access vlan 104
spanning-tree portfast
spanning-tree bpduguard enable
end

SW3# show spanning-tree interface fastethernet0/4 portfast
VLAN0104 enabled
```

The second half of the example confirms the configuration on the interface and the PortFast status. The **show running-config** command simply confirms that the switch recorded the two configuration commands. The **show spanning-tree interface fastethernet0/4 portfast** command lists the PortFast status of the interface; note that the status only shows up as enabled if PortFast is configured and the interface is up.

The alternative configuration works better when most of a switch's ports need PortFast and BPDU Guard. By default, switches disable both features on each interface. The alternative configuration lets you reverse the default, making the default for PortFast and BPDU Guard to be enabled on each interface. Then you have the option to disable the features of a port-by-port basis.

To change the defaults, use these two global commands:

- **spanning-tree portfast default**
- **spanning-tree portfast bpduguard default**

Then, to override the defaults, to disable the features, use these interface subcommands:

- **spanning-tree portfast disable**
- **spanning-tree bpduguard disable**

Configuring EtherChannel

As introduced back in Chapter 1, two neighboring switches can treat multiple parallel links between each other as a single logical link called an *EtherChannel*. STP operates on the EtherChannel, instead of the individual physical links, so that STP either forwards or blocks on the entire logical EtherChannel for a given VLAN. As a result, a switch in a forwarding state can then load balance traffic over all the physical links in the EtherChannel. Without EtherChannel, only one of the parallel links between two switches would be allowed to forward traffic, with the rest of the links blocked by STP.

EtherChannel may be one of the most challenging switch features to make work. First, the configuration has several options, so you have to remember the details of which options work together. Second, the switches also require a variety of other interface settings to match among all the links in the channel, so you have to know those settings as well.

This section focuses on the correct EtherChannel configuration. The later section titled "Troubleshooting EtherChannel" looks at many of the potential problems with EtherChannel, including all those other configuration settings that a switch checks before allowing the EtherChannel to work.

Configuring a Manual EtherChannel

The simplest way to configure an EtherChannel is to add the correct **channel-group** configuration command to each physical interface, on each switch, all with the **on** keyword. The **on** keyword tells the switches to place a physical interface into an EtherChannel.

Before getting into the configuration and verification, however, you need to start using three terms as synonyms: *EtherChannel*, *PortChannel*, and *Channel-group*. Oddly, IOS uses the **channel-group** configuration command, but then to display its status, IOS uses the **show etherchannel** command. Then, the output of this **show** command refers to neither an "EtherChannel" nor a "Channel-group," instead using the term "PortChannel." So, pay close attention to these three terms in the example.

To configure an EtherChannel manually, follow these steps:

Key Topic

Step 1. Add the **channel-group** *number* **mode on** interface subcommand under each physical interface that should be in the channel.

Step 2. Use the same number for all commands on the same switch, but the channel-group number on the neighboring switch can differ.

Example 2-7 shows a simple example, with two links between switches SW1 and SW2, as shown in Figure 2-6. The configuration shows SW1's two interfaces placed into channel-group 1, with two **show** commands to follow.

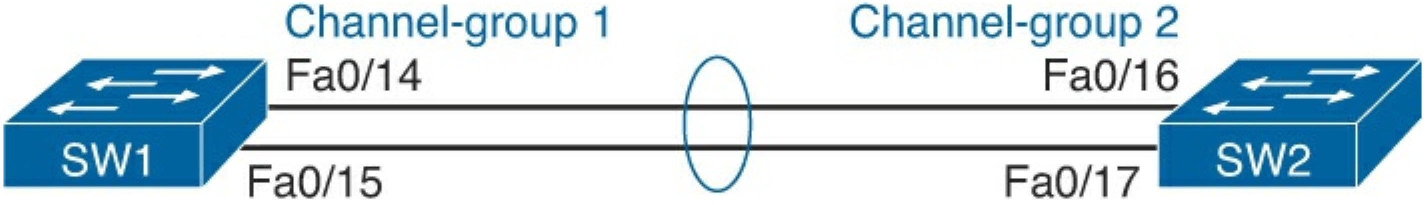

Channel-group 1
Channel-group 2
Fa0/14
Fa0/16
SW1
SW2
Fa0/15
Fa0/17

Figure 2-6. Sample LAN Used in EtherChannel Example

Example 2-7. Configuring and Monitoring EtherChannel

Click here to view code image

```
SW1# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
SW1(config)# interface fa 0/14
SW1(config-if)# channel-group 1 mode on
SW1(config)# interface fa 0/15
SW1(config-if)# channel-group 1 mode on
SW1(config-if)# ^Z

SW1# show spanning-tree vlan 3

VLAN0003
Spanning tree enabled protocol ieee
Root ID Priority 28675
Address 0019.e859.5380
Cost 12
Port 72 (Port-channel1)
Hello Time 2 sec Max Age 20 sec Forward Delay 15 sec

Bridge ID Priority 28675 (priority 28672 sys-id-ext 3)
Address 0019.e86a.6f80
Hello Time 2 sec Max Age 20 sec Forward Delay 15 sec
Aging Time 300

Interface Role Sts Cost Prio.Nbr Type
---------------- ---- --- --------- -------- --------------------------------
Po1 Root FWD 12 128.64 P2p Peer(STP)

SW1# show etherchannel 1 summary

Flags: D - down P - bundled in portchannel
I - stand-alone s - suspended
H - Hot-standby (LACP only)
R - Layer3 S - Layer2
U - in use f - failed to allocate aggregator

M - not in use, minimum links not met
u - unsuitable for bundling
w - waiting to be aggregated
d - default port


Number of channel-groups in use: 1
Number of aggregators: 1

Group Portchannel Protocol Ports
------+-------------+-----------+----------------------------------------------
1 Po1(SU) - Fa0/14(P) Fa0/15(P)
```

Take a few moments to look at the output in the two **show** commands in the example, as well. First, the **show spanning-tree** command lists Po1, short for PortChannel1, as an interface. This interface exists because of the **channel-group** commands using the **1** parameter. STP no longer operates on physical interfaces F0/14 and F0/15, instead operating on the PortChannel1 interface, so only that interface is listed in the output.

Next, note the output of the **show etherchannel 1 summary** command. It lists as a heading "Portchannel," with Po1 below it. It also lists both F0/14 and F0/15 in the list of ports, with a (P) beside each. Per the legend, the *P* means that the ports are bundled in the port channel, which is a code that means these ports have passed all the configuration checks and are valid to be included in the channel.

Configuring Dynamic EtherChannels

Cisco switches support two different protocols that allow the switches to negotiate whether a particular link becomes part of an EtherChannel or not. Basically, the configuration enables the protocol for a particular channel-group number. At that point, the switch can use the protocol to send messages to/from the neighboring switch and discover whether their configuration settings pass all checks. If a given physical link passes, the link is added to the EtherChannel and used; if not, it is placed in a down state, and not used, until the configuration inconsistency can be resolved.

For now, this section focuses on how to make it work, with the later "Troubleshooting EtherChannel" section focusing on these specific settings that can make it fail.

Cisco switches support the Cisco proprietary Port Aggregation Protocol (PAgP) and the IEEE standard Link Aggregation Control Protocol (LACP), based on IEEE standard 802.3ad. Although differences exist between the two, to the depth discussed here, they both accomplish the same task: negotiate so that only links that pass the configuration checks are actually used in an EtherChannel.

To configure either protocol, a switch uses the **channel-group** configuration commands on each switch, but with a keyword that either means "use this protocol and begin negotiations" or "use this protocol and wait for the other switch to begin negotiations." As shown in Figure 2-7, the **desirable** and **auto** keywords enable PAgP, and the **active** and **passive** keywords enable LACP. With these options, at least one side has to begin the negotiations. In other words, with PAgP, at least one of the two sides must use **desirable**, and with LACP, at least one of the two sides must use **active**.

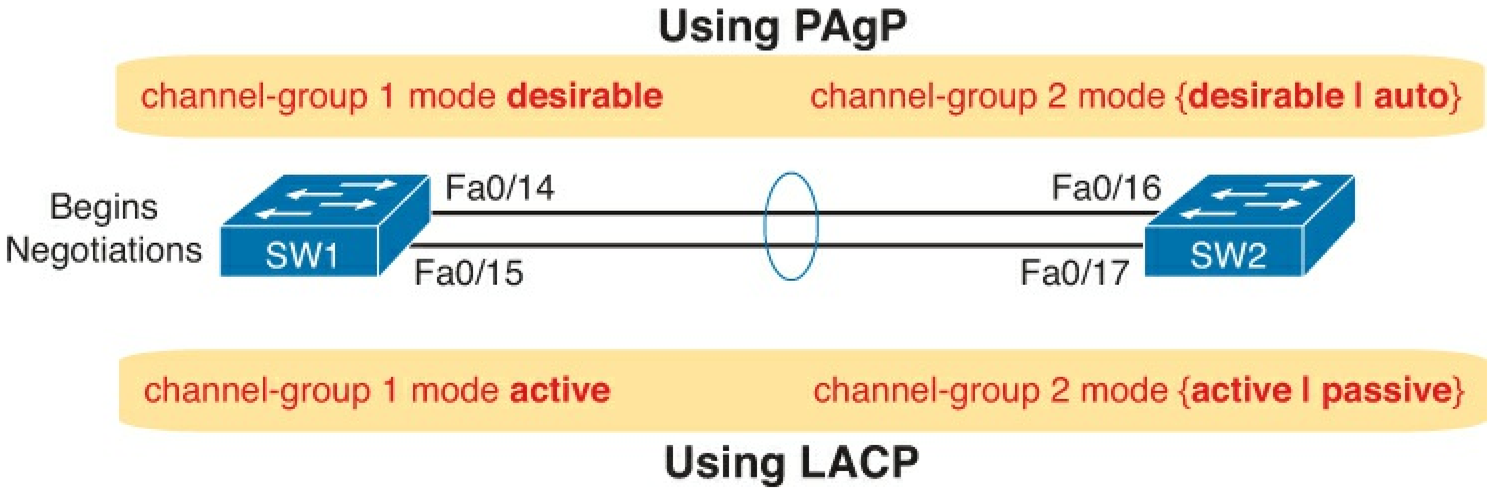

Using PAgP
channel-group 1 mode desirable
channel-group 2 mode {desirable | auto}
Begins Negotiations
SW1
Fa0/14
Fa0/15
Fa0/16
Fa0/17
SW2
channel-group 1 mode active
channel-group 2 mode {active | passive}
Using LACP

Figure 2-7. Correct EtherChannel Configuration Combinations

> **Note**
>
> Do not use the **on** parameter on one end, and either **auto** or **desirable** (or for LACP, **active** or **passive**) on the neighboring switch. The **on** option uses neither PAgP nor LACP, so a configuration that uses **on**, with PAgP or LACP options on the other end, would prevent the EtherChannel from working.

For instance, you could replace the configuration in Example 2-7 with **channel-group 1 mode desirable** for both interfaces, with SW2 using **channel-group 2 mode auto**.

STP Troubleshooting

The final section of this chapter focuses on how to apply the information covered in Chapter 1 and in the first half of this chapter. Although this section helps you prepare to troubleshoot STP problems in real networks, the main goal for this section is to prepare you to answer STP questions on the CCNA exams.

STP questions tend to intimidate many test takers. STP uses many rules, with tiebreakers in case one rule ends with a tie. Without much experience with STP, people tend to distrust their own answers. Also, even those of us with networking jobs already probably do not troubleshoot STP very often, because STP runs by default and works well using default configuration settings in medium to small networks, so engineers seldom need to troubleshoot STP problems. So, STP begs for a good troubleshooting strategy before examining a complex STP question.

This section reviews the rules for STP, while emphasizing some important troubleshooting points. In particular, this section takes a closer look at the tiebreakers that STP uses to make decisions. It also makes some practical suggestions about how to go about answering exam questions such as "which switch is the root switch."

Determining the Root Switch

Determining the STP root switch is easy if you know all the switches' BIDs: Just pick the lowest value. If the question lists the priority and MAC address separately, as is common in some **show** command output, pick the switch with the lowest priority, or in the case of a tie, pick the lower MAC address value.

And just to be extra clear, STP does not have nor need a tiebreaker for electing the root switch. The BID uses a switch universal MAC address as the last 48 bits of the BID. These MAC addresses are unique in the universe, so there should never be identical BIDs, with no need for a tiebreaker.

For the exam, a question that asks about the root switch might not be so simple as listing a bunch of BIDs and asking you which one is "best." A more likely question is a sim question in which you have to do any **show** commands you like or a multiple choice question that lists the output from only one or two commands. Then you have to apply the STP algorithm to figure out the rest.

When faced with an exam question using a simulator, or just the output in an exhibit, use a simple strategy of ruling out switches, as follows:

Key Topic

Step 1. Begin with a list or diagram of switches, and consider all as possible root switches.

Step 2. Rule out any switches that have an RP (**show spanning-tree**, **show spanning-tree root**), because root switches do not have a RP.

Step 3. Always try **show spanning-tree**, because it identifies the local switch as root directly: "This switch is the root" on the fifth line of output.

Step 4. Always try **show spanning-tree root**, because it identifies the local switch as root indirectly: The RP column is empty if the local switch is the root.

Step 5. When using a sim, rather than try switches randomly, chase the RPs. For example, if starting with SW1, and SW1's G0/1 is an RP, next try the switch on the other end of SW1's G0/1 port.

Step 6. When using a Sim, using **show spanning-tree vlan** *x* on a few switches, and recording the root switch, RP, and DP ports can quickly show you most STP facts. Use that strategy if available.

The one step in this list that most people ignore is the idea of ruling out switches that have an RP. Root switches do not have an RP, so any switch with an RP can be ruled out as not being the root switch for that VLAN. Example 2-8 shows two commands on switch SW2 in some LAN that confirms that SW2 has an RP and is therefore not the root switch.

Example 2-8. Ruling Out Switches as Root Based on Having a Root Port

Click here to view code image

```
SW2# show spanning-tree vlan 20 root

Root Hello Max Fwd
Vlan Root ID Cost Time Age Dly Root Port
---------------- -------------------- --------- ----- --- --- ------------
VLAN0020 32788 1833.9d7b.0e80 4 2 20 15 Gi0/2

SW2# show spanning-tree vlan 20

VLAN0020
Spanning tree enabled protocol ieee
Root ID Priority 32788
Address 1833.9d7b.0e80
Cost 4
Port 26 (GigabitEthernet0/2)
Hello Time 2 sec Max Age 20 sec Forward Delay 15 sec

Bridge ID Priority 32788 (priority 32768 sys-id-ext 20)
Address 1833.9d7b.1380
Hello Time 2 sec Max Age 20 sec Forward Delay 15 sec
Aging Time 15 sec

Interface Role Sts Cost Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------------
Gi0/1 Desg FWD 4 128.25 P2p
Gi0/2 Root FWD 4 128.26 P2p
```

Both commands identify SW2's G0/2 port as its RP, so if you follow the suggestions, the next switch to try in a sim question would be the switch on the other end of SW2's G0/2 interface.

Determining the Root Port on Nonroot Switches

Determining the RP of a switch when **show** command output is available is relatively easy. As shown recently in Example 2-7, both **show spanning-tree** and **show spanning-tree root** list the root port of the local switch, assuming it is not the root switch. The challenge comes more when an exam question makes you think through how the switches choose the RP based on the root cost of each path to the root switch with some tiebreakers as necessary.

As a review, each nonroot switch has one, and only one, RP for a VLAN. To choose its RP, a switch listens for incoming hello bridge protocol data units (BPDU). For each received hello, the switch adds the cost listed in the hello BPDU to the cost of the incoming interface (the interface on which the hello was received). That total is the root cost over that path. The lowest root cost wins, and the local switch uses its local port that is part of the least root cost path as its root port.

Although that description has a lot of twists and turns in the words, it is the same concept described for Chapter 1's Figure 1-8.

For the exam, if the question has a diagram of the LAN, most humans work better with a slightly different way to look at the problem. Instead of thinking about hello messages and so on, approach the question as this: the sum of all outgoing port costs between the nonroot switch and the root. Repeating a familiar example, with a twist, Figure 2-8 shows the calculation of the root cost. Note that SW3's Gi0/3 port has yet again had its cost configured to a different value.

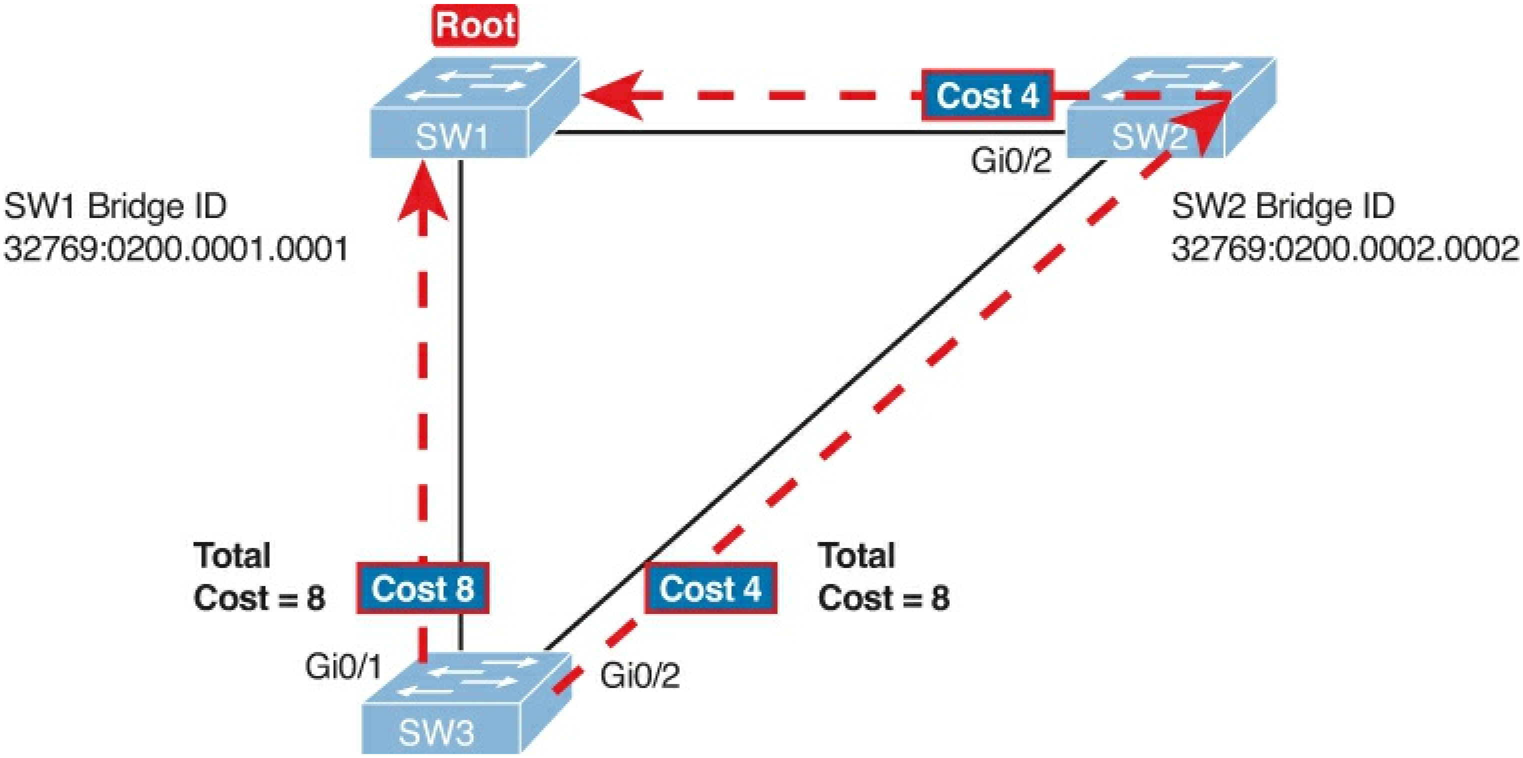


Figure 2-8. SW3's Root Cost Calculation Ends in a Tie

STP Tiebreakers When Choosing the Root Port

The figure shows the easier process of adding the STP costs of the outgoing interfaces over each from SW3, a nonroot, to SW1, the root. It also shows a tie (on purpose), to talk about the tiebreakers.

When a switch chooses its root port, the first choice is to choose the local port that is part of the least root cost path. When those costs tie, the switch picks the port connected to the neighbor with the lowest BID. This tiebreaker usually breaks the tie, but not always. So, for completeness, the three tiebreakers are, in the order a switch uses them, as follows:

1. Choose based on the lowest neighbor bridge ID.
2. Choose based on the lowest neighbor port priority.
3. Choose based on the lowest neighbor internal port number.

(Note that the switch only considers the root paths that tie when thinking about these tiebreakers.)

For example, Figure 2-8 shows that SW3 is not root and that its two paths to reach the root tie with their root costs of 8. The first tiebreaker is the lowest neighbor's BID. SW1's BID value is lower than SW2's, so SW3 chooses its G0/1 interface as its RP in this case.

The last two RP tiebreakers come into play only when two switches connect to each other with multiple links, as shown in Figure 2-9. In that case, a switch receives hellos on more than one port from the same neighboring switch, so the BIDs tie.

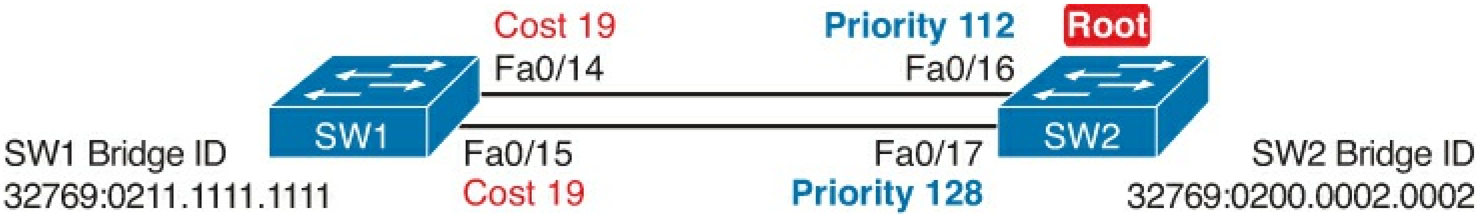


Figure 2-9. Topology Required for the Last Two Tiebreakers for Root Port

In this particular example, SW2 becomes root, and SW1 needs to choose its RP. SW1's port costs tie, at 19 each, so SW1's root cost over each path will tie at 19. SW2 sends hellos over each link to SW1, so SW1 cannot break the tie based on SW1's neighbor BID because both list SW2's BID. So, SW1 has to turn to the other two tiebreakers.

> **Note**
>
> In real life, most engineers would put these two links into an EtherChannel.

The next tiebreaker is a configurable option: the neighboring switch's port priority on each neighboring switch interface. Cisco switch ports default to a setting of 128, with a range of values from 0 through 255, with lower being better (as usual). In this example, the network engineer has set SW2's F0/16 interface with the **spanning-tree vlan 10 port-priority 112** command. SW1 learns that the neighbor has a port priority of 112 on the top link and 128 on the bottom, so SW1 uses its top (F0/14) interface as the root port.

If the port priority ties, which it often does due to the default values, STP relies on an internal port numbering on the neighbor.

Cisco switches assign an internal integer to identify each interface on the switch. The nonroot looks for the neighbor's lowest internal port number (as listed in the hello messages) and chooses its RP based on the lower number.

Cisco switches use an obvious numbering, with Fa0/1 having the lowest number, then Fa0/2, then Fa0/3, and so on. So, in Figure SW2, SW2's Fa0/16 would have a lower internal port number than Fa0/17; SW1 would learn those numbers in the hello; and SW1 would use its Fa0/14 port as its RP.

Suggestions for Attacking Root Port Problems on the Exam

Exam questions that make you think about the RP can be easy if you know where to look and the output of a few key commands are available. However, the more conceptual the question, the more you have to calculate the root cost over each path, correlate that to different **show** commands, and put the ideas together. The following list makes a few suggestions about how to approach STP problems on the exam:

Key Topic

1. If available, look at the **show spanning-tree** and **show spanning-tree root** commands. These both list the root port, and the first of these also lists the root cost (see Example 2-7).
2. The **show spanning-tree** command list cost in two places: the root cost at the top, in the section about the root switch; and the interface cost, at the bottom, in the per-interface section. Be careful, though; the cost at the bottom is the interface cost, not the root cost!
3. For problems where you have to calculate a switch's root cost:
   - **a.** Memorize the default cost values: 100 for 10 Mbps, 19 for 100 Mbps, 4 for 1 Gbps, and 2 for 10 Gbps.
   - **b.** Look for any evidence of the **spanning-tree cost** configuration command on an interface, because it overrides the default cost. Do not assume default costs are used.
   - **c.** When you know a default cost is used, if you can, check the current actual speed as well. Cisco switches choose STP cost defaults based on the current speed, not the maximum speed.

Determining the Designated Port on Each LAN Segment

Each LAN segment has a single switch that acts as the designated port (DP) on that segment. On segments that connect a switch to a device that does not even use STP—for example, segments connecting a switch to a PC or a router—the switch always wins, because it is the only device sending a hello onto the link. However, links with two switches require a little more work to discover which should be the DP. By definition:

Key Topic

Step 1. For switches connected to the same LAN segment, the switch with the lowest cost to reach the root, as advertised in the hello they send onto the link, becomes the DP on that link.

Step 2. In case of a tie, among the switches that tied on cost, the switch with the lowest BID becomes the DP.

For example, consider Figure 2-10. This figure notes the root, RPs, and DPs and each switch's least cost to reach the root over its respective RP.

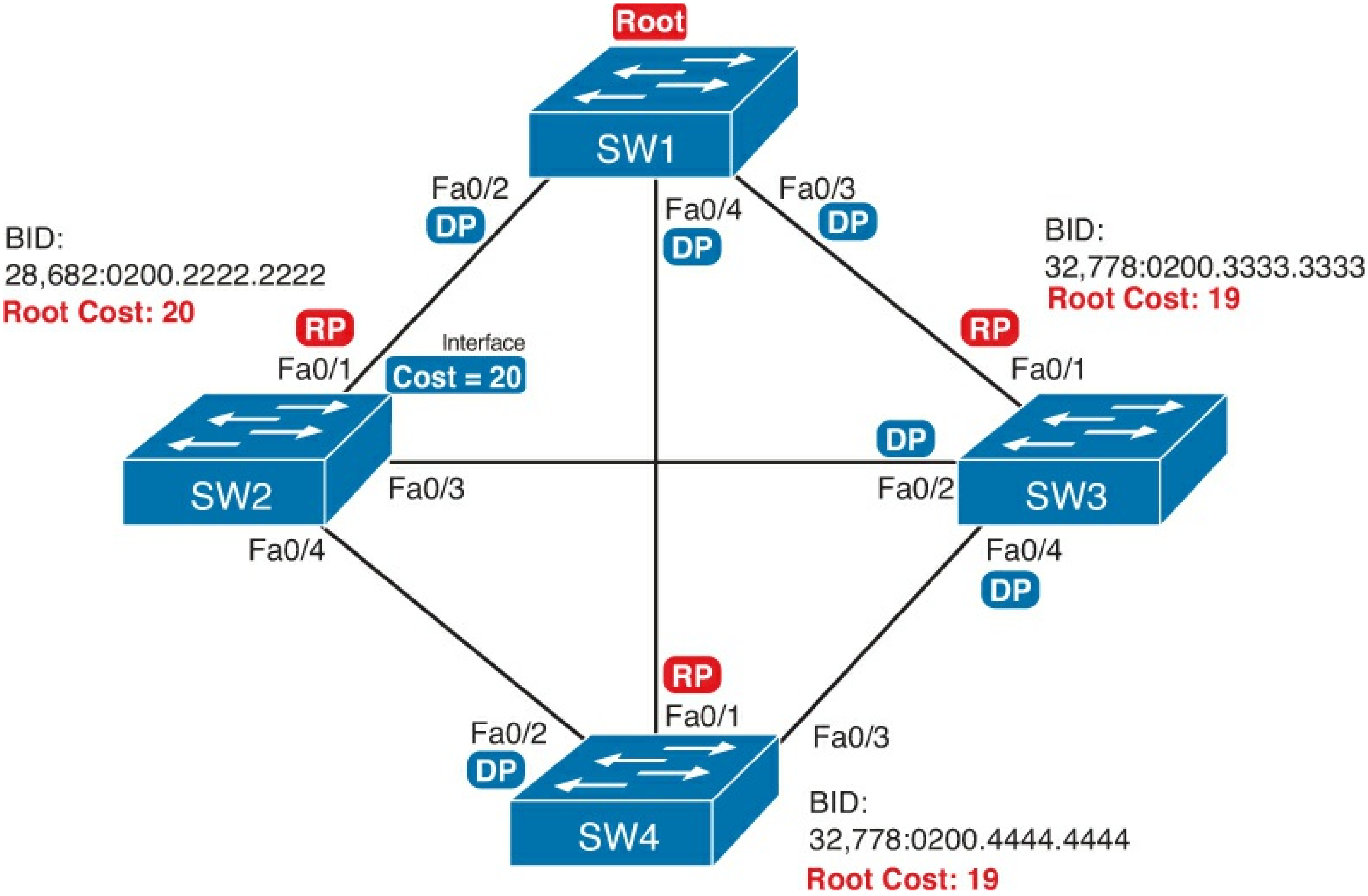

Root
SW1
Fa0/2
DP
Fa0/4
DP
Fa0/3
DP
BID:
28,682:0200.2222.2222
Root Cost: 20
RP
Fa0/1
Interface
Cost = 20
SW2
Fa0/3
Fa0/4
BID:
32,778:0200.3333.3333
Root Cost: 19
RP
Fa0/1
DP
Fa0/2
SW3
Fa0/4
DP
RP
Fa0/1
Fa0/2
DP
Fa0/3
SW4
BID:
32,778:0200.4444.4444
Root Cost: 19

Figure 2-10. Picking the DPs

Focus on the segments that connect the nonroot switches for a moment.

SW2–SW4 segment: SW4 wins because of its root cost of 19, compared to SW2's root cost of 20.

SW2-SW3 segment: SW3 wins because of its root cost of 19, compared to SW2's root cost of 20.

SW3-SW4 segment: SW3 and SW4 tie on root cost, both with root cost 19. SW3 wins due to its better (lower) BID value.

Interestingly, SW2 loses and does not become DP on the links to SW3 and SW4 even though SW2 has the better (lower) BID value. The DP tiebreaker does use the lowest BID, but the first DP criteria is the lowest root cost, and SW2's root cost happens to be higher than SW3's and SW4's.

Note

A single switch can connect two or more interfaces to the same collision domain, and compete to become DP, if hubs are used. In such cases, two different switch ports on the same switch tie, the DP choice uses the same two final tiebreakers as used with the RP selection: the lowest interface STP priority, and if that ties, the lowest internal interface number.

Suggestions for Attacking Designated Port Problems on the Exam

As with exam questions asking about the RP, exam questions that make you think about the DP can be easy if you know where to look and the output of a few key commands are available. However, the more conceptual the question, the more you have to think about the criteria for choosing the DP: first the root cost of the competing switches, and then the better BID if they tie based on root cost.

The following list gives some tips to keep in mind when digging into a given DP issue. Some of this list repeats the suggestions for finding the RP, but to be complete, this list includes each idea as well.

Key Topic

1. If available, look at the **show spanning-tree** commands, at the list of interfaces at the end of the output. Then, look for the Role column, and look for Desg, to identify any DPs.
2. Identify the root cost of a switch directly by using the **show spanning-tree** command. But be careful! This command lists the cost in two places, and only the mention at the top, in the section about the root, lists the root cost.

3. For problems where you have to calculate a switch's root cost, do the following:
   a. Memorize the default cost values: 100 for 10 Mbps, 19 for 100 Mbps, 4 for 1 Gbps, and 2 for 10 Gbps.
   b. Look for any evidence of the **spanning-tree cost** configuration command on an interface, because it overrides the default cost. Do not assume default costs are used.
   c. When you know a default cost is used, if you can, check the current actual speed as well. Cisco switches choose STP cost defaults based on the current speed, not the maximum speed.

STP Convergence

STP puts each RP and DP into a forwarding state, and ports that are neither RP nor DP into a blocking state. Those states may remain as is for days, weeks, or months. But at some point, some switch or link will fail, a link may change speeds (changing the STP cost), or the STP configuration may change. Any of these events can cause switches to repeat their STP algorithm, which may in turn change their own RP and any ports that are DPs.

When STP converges based on some change, not all the ports have to change their state. For instance, a port that was forwarding, if it still needs to forward, just keeps on forwarding. Ports that were blocking that still need to block keep on blocking. But when a port needs to change state, something has to happen, based on the following rules:

Key Topic

- For interfaces that stay in the same STP state, nothing needs to change.
- For interfaces that need to move from a forwarding state to a blocking state, the switch immediately changes the state to blocking.
- For interfaces that need to move from a blocking state to a forwarding state, the switch first moves the interface to listening state, then learning state, each for the time specified by the forward delay timer (default 15 seconds). Only then is the interface placed into forwarding state.

Because the transition from blocking to forwarding does require some extra steps, you should be ready to respond to conceptual questions about the transition. To be ready, review the section "Reacting to Changes in the Network," in Chapter 1.

Troubleshooting EtherChannel

EtherChannels can prove particularly challenging to troubleshoot for a couple of reasons. First, you have to be careful to match the correct configuration, and there are many more incorrect configuration combinations than there are correct combinations. Second, many interface settings must match on the physical links, both on the local switch and on the neighboring switch, before a switch will add the physical link to the channel. This last topic in the chapter works through both sets of issues.

Incorrect Options on the channel-group Command

Earlier, the section titled "Configuring EtherChannel" listed the small set of working configuration options on the **channel-group** command. Those rules can be summarized as follows, for a single EtherChannel:

Key Topic

1. On the local switch, all the **channel-group** commands for all the physical interfaces must use the same channel-group number.
2. The **channel-group** number can be different on the neighboring switches.
3. If using the **on** keyword, you must use it on the corresponding interfaces of both switches.
4. If you use the **desirable** keyword on one switch, the switch uses PAgP; the other switch must use either **desirable** or **auto.**
5. If you use the **active** keyword on one switch, the switch uses LACP; the other switch must use either **active** or **passive.**

These rules summarize the correct configuration options, but the options actually leave many more incorrect choices. The following list shows some incorrect configurations that the switches allow, even though they would result in the EtherChannel not working. The list compares the configuration on one switch to another based on the physical interface configuration. Each lists the reasons why the configuration is incorrect:

- Configuring the **on** keyword on one switch, and **desirable**, **auto**, **active**, or **passive** on the other switch. The **on** keyword does not enable PAgP, and does not enable LACP, and the other options rely on PAgP or LACP.
- Configuring the **auto** keyword on both switches. Both use PAgP, but both wait on the other switch to begin negotiations.
- Configuring the **passive** keyword on both switches. Both use LACP, but both wait on the other switch to begin negotiations.
- Configuring the **active** keyword on one switch and either **desirable** or **auto** on the other switch. The **active** keyword uses LACP, whereas the other keywords use PAgP.

- Configuring the **desirable** keyword on one switch and either **active** or **passive** on the other switch. The **desirable** keyword uses PAgP, whereas the other keywords use LACP.

Example 2-9 shows an example that matches the last item in the list. In this case, SW1's two ports (F0/14 and F0/15) have been configured with the **desirable** keyword, and SW2's matching F0/16 and F0/17 have been configured with the **active** keyword. The example lists some telling status information about the failure, with notes following the example.

Example 2-9. Ruling Out Switches as Root Based on Having a Root Port

Click here to view code image

```
SW1# show etherchannel summary
Flags: D - down P - bundled in portchannel
I - stand-alone s - suspended
H - Hot-standby (LACP only)
R - Layer3 S - Layer2
U - in use f - failed to allocate aggregator

M - not in use, minimum links not met
u - unsuitable for bundling
w - waiting to be aggregated
d - default port


Number of channel-groups in use: 1
Number of aggregators: 1

Group Portchannel Protocol Ports
------+-------------+-----------+-----------------------------------------------
1 Po1(SD) PAgP Fa0/14(I) Fa0/15(I)

SW1# show interfaces status | include Po|14|15
Port Name Status Vlan Duplex Speed Type
Fa0/14 connected 301 a-full a-100 10/100BaseTX
Fa0/15 connected 301 a-full a-100 10/100BaseTX
Po1 notconnect unassigned auto auto
```

Start at the top, in the legend of the **show etherchannel summary** command. The *D* code letter means that the channel itself is down, with *S* meaning that the channel is a Layer 2 EtherChannel. Code *I* means that the physical interface is working independently from the PortChannel (described as "stand-alone"). Then, the bottom of that command's output highlights Portchannel (Po1) as Layer 2 EtherChannel in a down state (SD), with F0/14 and F0/15 as stand-alone interfaces (I).

Interestingly, because the problem is a configuration mistake, the two physical interfaces still operate independently, as if the port channel did not exist. The last command in the example shows that while the Portchannel 1 interface is down, the two physical interfaces are in a connected state.

Note

As a suggestion for attacking EtherChannel problems on the exam, rather than memorizing all the incorrect configuration options, concentrate on the list of correct configuration options. Then look for any differences between a given question's configuration as compared to the known correct configurations and work from there.

Configuration Checks Before Adding Interfaces to EtherChannels

Even when the **channel-group** commands have all been configured correctly, other configuration settings can cause problems as well. This last topic examines those configuration settings and their impact.

First, a local switch checks each new physical interface that is configured to be part of an EtherChannel, comparing each new link to the existing links. That new physical interface's settings must be the same as the existing links; otherwise, the switch does not add the new link to the list of approved and working interfaces in the channel. That is, the physical interface remains configured as part of the port channel, but it is not used as part of the channel, often being placed into some nonworking state.

The list of items the switch checks includes the following:

Key Topic

- Speed
- Duplex

- Operational access or trunking state (all must be access, or all must be trunks)
- If an access port, the access VLAN
- If a trunk port, the allowed VLAN list (per the **switchport trunk allowed** command)
- If a trunk port, the native VLAN
- STP interface settings

In addition, switches check the settings on the neighboring switch. To do so, the switches either use PAgP or LACP (if already in use), or Cisco Discovery Protocol (CDP) if using manual configuration. The neighbor must match on all parameters in this list except the STP settings.

As an example, SW1 and SW2 again use two links in one EtherChannel. Before configuring the EtherChannel, SW1's F0/15 was given a different STP port cost than F0/14. Example 2-10 picks up the story just after configuring the correct **channel-group** commands, when the switch is deciding whether to use F0/14 and F0/15 in this EtherChannel.

Example 2-10. Local Interfaces Fail in EtherChannel Because of Mismatched STP Cost

Click here to view code image

```
*Mar 1 23:18:56.132: %PM-4-ERR_DISABLE: channel-misconfig (STP) error detected on
Po1, putting Fa0/14 in err-disable state
*Mar 1 23:18:56.132: %PM-4-ERR_DISABLE: channel-misconfig (STP) error detected on
Po1, putting Fa0/15 in err-disable state
*Mar 1 23:18:56.132: %PM-4-ERR_DISABLE: channel-misconfig (STP) error detected on
Po1, putting Po1 in err-disable state
*Mar 1 23:18:58.120: %LINK-3-UPDOWN: Interface FastEthernet0/14, changed state to down
*Mar 1 23:18:58.137: %LINK-3-UPDOWN: Interface Port-channel1, changed state to down
*Mar 1 23:18:58.137: %LINK-3-UPDOWN: Interface FastEthernet0/15, changed state to down

SW1# show etherchannel summary
Flags: D - down P - bundled in portchannel
I - stand-alone s - suspended
H - Hot-standby (LACP only)
R - Layer3 S - Layer2
U - in use f - failed to allocate aggregator

M - not in use, minimum links not met
u - unsuitable for bundling
w - waiting to be aggregated
d - default port


Number of channel-groups in use: 1
Number of aggregators: 1

Group Portchannel Protocol Ports
------+-------------+-----------+-----------------------------------------------
1 Po1(SD) - Fa0/14(D) Fa0/15(D)
```

The messages at the top of the example specifically state what the switch does when thinking about whether the interface settings match. In this case, SW1 detects the different STP costs. SW1 does not use F0/14, does not use F0/15, and even places them into an err-disabled state. The switch also puts the PortChannel into err-disabled state. As a result, the Port Channel is not operational, and the physical interfaces are also not operational.

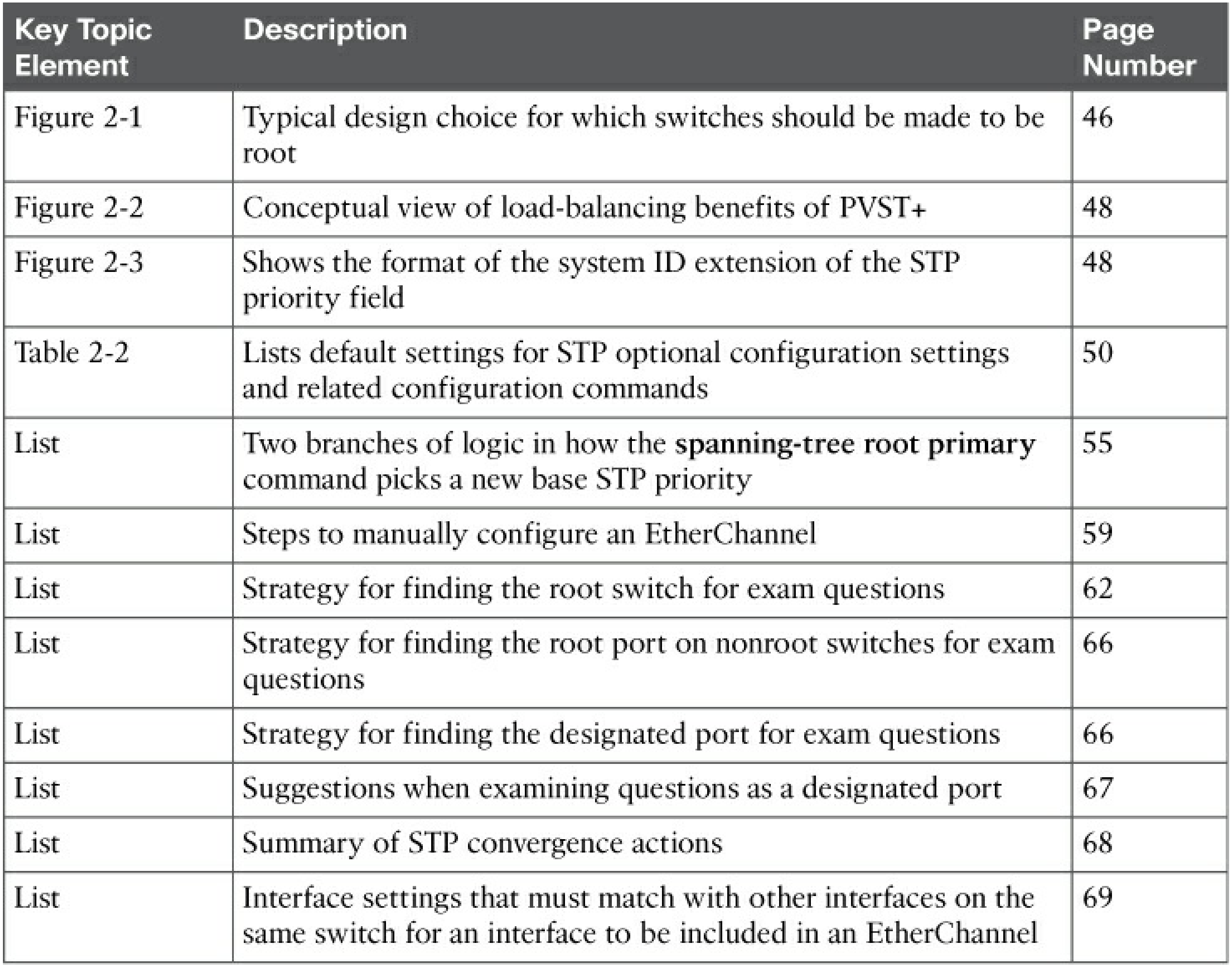
To solve this problem, you must reconfigure the physical interfaces to use the same STP settings. In addition, the portchannel and physical interfaces must be **shutdown**, and then **no shutdown**, to recover from the err-disabled state. (Note that when a switch applies the **shutdown** and **no shutdown** commands to a port channel, it applies those same commands to the physical interfaces, as well; so, just do the **shutdown**/**no shutdown** on the portchannel interface.)

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 2-3 lists these key topics and where each is discussed.

Table 2-3. Key Topics for Chapter 2



Key Topic Element	Description	Page Number
Figure 2-1	Typical design choice for which switches should be made to be root	46
Figure 2-2	Conceptual view of load-balancing benefits of PVST+	48
Figure 2-3	Shows the format of the system ID extension of the STP priority field	48
Table 2-2	Lists default settings for STP optional configuration settings and related configuration commands	50
List	Two branches of logic in how the **spanning-tree root primary** command picks a new base STP priority	55
List	Steps to manually configure an EtherChannel	59
List	Strategy for finding the root switch for exam questions	62
List	Strategy for finding the root port on nonroot switches for exam questions	66
List	Strategy for finding the designated port for exam questions	66
List	Suggestions when examining questions as a designated port	67
List	Summary of STP convergence actions	68
List	Interface settings that must match with other interfaces on the same switch for an interface to be included in an EtherChannel	69

Definitions of Key Terms

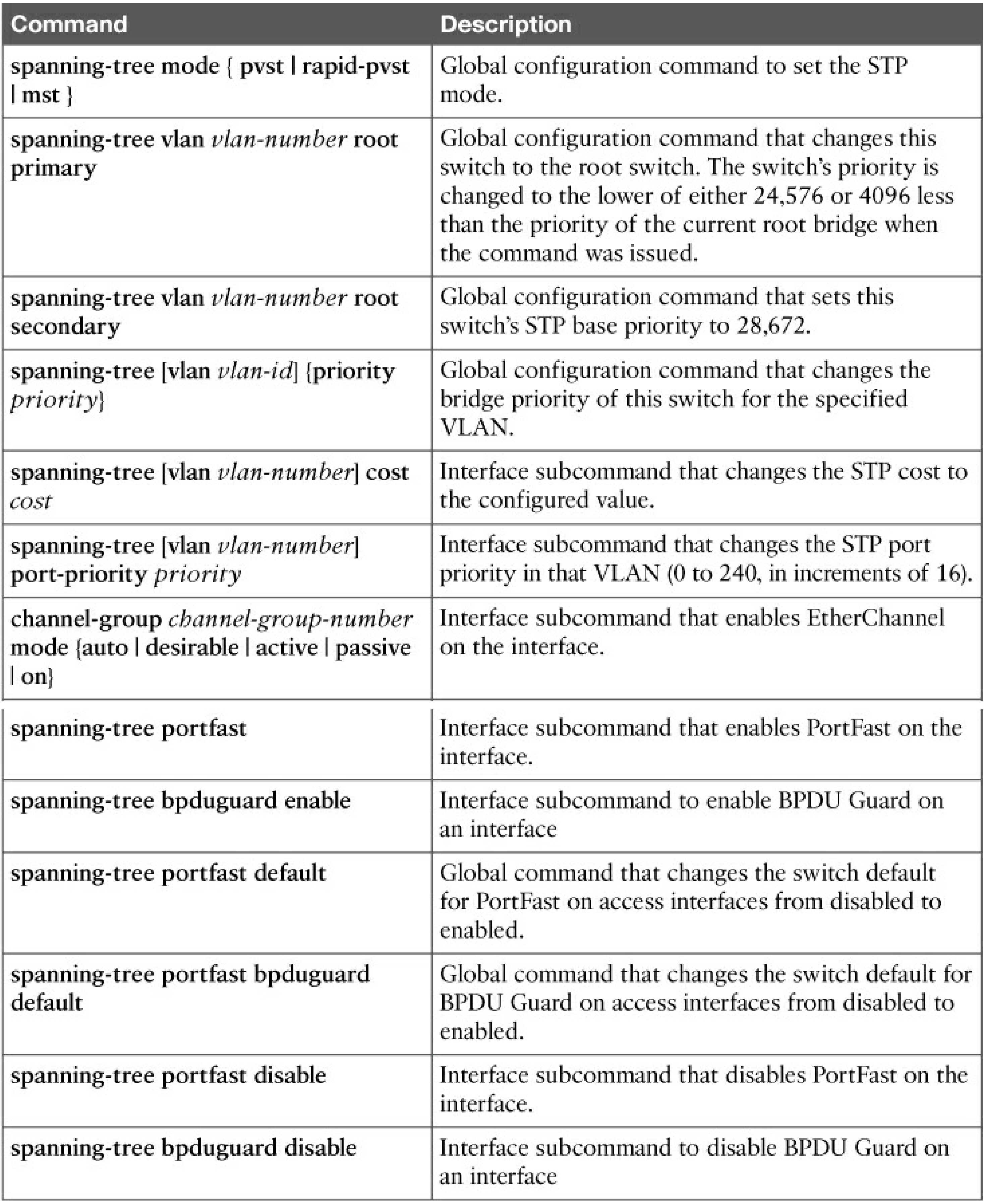
After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22 directs you in how to use these terms for late-stage preparation for the exam.

Rapid PVST+
PVST+
system ID extension
PAgP
LACP
PortChannel
Channel Group

Command Reference to Check Your Memory

Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To check to see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table with a piece of paper, read the descriptions on the right side, and see whether you remember the command.

Table 2-4. Chapter 2 Configuration Command Reference



Command	Description
spanning-tree mode { **pvst** | **rapid-pvst** | **mst** }	Global configuration command to set the STP mode.
spanning-tree vlan *vlan-number* **root primary**	Global configuration command that changes this switch to the root switch. The switch's priority is changed to the lower of either 24,576 or 4096 less than the priority of the current root bridge when the command was issued.
spanning-tree vlan *vlan-number* **root secondary**	Global configuration command that sets this switch's STP base priority to 28,672.
spanning-tree [**vlan** *vlan-id*] {**priority** *priority*}	Global configuration command that changes the bridge priority of this switch for the specified VLAN.
spanning-tree [**vlan** *vlan-number*] **cost** *cost*	Interface subcommand that changes the STP cost to the configured value.
spanning-tree [**vlan** *vlan-number*] **port-priority** *priority*	Interface subcommand that changes the STP port priority in that VLAN (0 to 240, in increments of 16).
channel-group *channel-group-number* **mode** {**auto** | **desirable** | **active** | **passive** | **on**}	Interface subcommand that enables EtherChannel on the interface.
spanning-tree portfast	Interface subcommand that enables PortFast on the interface.
spanning-tree bpduguard enable	Interface subcommand to enable BPDU Guard on an interface
spanning-tree portfast default	Global command that changes the switch default for PortFast on access interfaces from disabled to enabled.
spanning-tree portfast bpduguard default	Global command that changes the switch default for BPDU Guard on access interfaces from disabled to enabled.
spanning-tree portfast disable	Interface subcommand that disables PortFast on the interface.
spanning-tree bpduguard disable	Interface subcommand to disable BPDU Guard on an interface

Table 2-5. Chapter 2 EXEC Command Reference

Command	Description
show spanning-tree	Lists details about the state of STP on the switch, including the state of each port
show spanning-tree *interface interface-id*	Lists STP information only for the specified port
show spanning-tree vlan *vlan-id*	Lists STP information for the specified VLAN
show spanning-tree [**vlan** *vlan-id*] **root**	Lists information about each VLAN's root or for just the specified VLAN
show spanning-tree [**vlan** *vlan-id*] **bridge**	Lists STP information about the local switch for each VLAN or for just the specified VLAN
debug spanning-tree events	Causes the switch to provide informational messages about changes in the STP topology
show spanning-tree interface *type number* **portfast**	Lists a one-line status message about PortFast on the listed interface
show etherchannel [*channel-group-number*] {**brief** | **detail** / **port** | **port-channel** | **summary**}	Lists information about the state of EtherChannels on this switch

Chapter 3. Troubleshooting LAN Switching

This chapter covers the following exam topics:

Troubleshooting

Identify and correct common network problems

Troubleshoot and resolve interVLAN routing problems

- Native VLAN
- Port mode trunk status

This troubleshooting chapter, along with several other entire chapters and other sections of chapters, has an important job: to help you develop the troubleshooting skills required to quickly and confidently answer certain types of questions on the exams. At the same time, this chapter should make you better prepared to solve real networking problems.

The troubleshooting chapters and sections in this book do not have the same primary goal as the other materials. Simply put, the nontroubleshooting topics focus on individual features and facts about an area of technology. Troubleshooting topics pull a much broader set of concepts together. These troubleshooting chapters take a broader look at the networking world, focusing on how the parts work together, assuming that you already know about the individual components.

This chapter has one obvious goal and one not-so-obvious goal. First, it discusses how to troubleshoot LANs. Not so obvious is that this chapter also reviews many of the pre-requisite Ethernet LAN topics for this book. Chapter 1, "Spanning Tree Protocol Concepts," reviewed some of the topics, and this chapter reviews many others, while also showing how to use both old and new topics to troubleshoot Ethernet LAN topics.

This long chapter breaks the materials into three sections, as follows:

- "Generalized Troubleshooting Methodologies"
- "Troubleshooting the LAN Switching Data Plane"
- "Troubleshooting Examples and Exercises"

Given the length, consider breaking each of the three major sections into a separate reading session; they are approximately 10, 20, and 20 pages in length, respectively. All three sections are related, so they are in the same chapter, but the middle section contains the core LAN switch troubleshooting topics. The first section defines some troubleshooting terms before diving into the first entire chapter on network troubleshooting. And the final section is essentially two long examples, with plenty of **show** commands. These long examples should help you build some skills at thinking through what the **show** commands mean on Cisco switches.

"Do I Know This Already?" Quiz

Because the troubleshooting chapters of this book pull in concepts from many other chapters, including some chapters in *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*, and show how to approach some of the more challenging questions on the CCNA exams, you should read these chapters regardless of your current knowledge level. For these reasons, the troubleshooting chapters do not include a "Do I Know This Already?" quiz. However, if you feel particularly confident about troubleshooting LAN switching features covered in this book and *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*, feel free to move to the "Exam Preparation Tasks" section, near the end of this chapter, to bypass the majority of the chapter.

Foundation Topics

Generalized Troubleshooting Methodologies

Note

The generic troubleshooting strategies and methods described here are a means to an end. You do not need to study these processes or memorize them for the purposes of the exam. Instead, these processes can help you think through problems on the exam so that you can answer the questions a little more quickly and with a little more confidence.

When faced with a need to solve a networking problem, everyone uses some troubleshooting methodology, whether informal or formal. Some people like to start by checking the physical cabling or by checking the interface status of all the physical links that could affect the problem. Some people like to start by pinging everything that could tell you more about the problem and then drilling deeper into the details. Some people might even just try whatever comes to mind until they intuitively know the general problem. None of these methods is inherently bad or good; I've tried all these methods, and others, and had some success with each approach.

Most people develop troubleshooting habits and styles that work well based on their own experiences and strengths. However, when learning about troubleshooting, or learning about how to troubleshoot a particular area of expertise, a more systematic troubleshooting methodology can help anyone learn to troubleshoot problems with better success. The following sections describe one such systematic troubleshooting methodology for the purpose of helping you prepare for the CCNA exams.

This troubleshooting methodology has three major branches, which generally occur in the order shown here:

- **Analyzing/predicting normal operation:** This step answers this question: What should happen in this network? This step results in a description and prediction of the details of what should happen if the network is working correctly, based on documentation, configuration, and **show** and **debug** command output.
- **Problem isolation:** This step keeps answering the same question: What specifically is not working? When some problem might be occurring, find the components that do not work correctly as compared to the predicted behavior. Then find out what might be causing that problem and so on. The answers are again based on documentation, configuration, and **show** and **debug** command output.
- **Root cause analysis:** This step answers this question: What can we fix that solves the problem? This step identifies the underlying causes of the problems identified in the previous step, specifically the causes that have a specific action with which the problem can be fixed.

Following these three steps should result in the engineer knowing how to fix the problem, not just the problem symptoms. Next, the text explains some thoughts about how to approach each step of the troubleshooting process.

Analyzing and Predicting Normal Network Operation

Any network's job is to deliver data from one end-user device to another. To analyze a network, an engineer needs to understand the logic used by each successive device as it forwards the data to the next device. By thinking about what should happen at each device, the engineer can describe the entire flow of data.

The term *data plane* refers to actions devices take to forward data. To forward each frame or packet, a device applies its data plane logic and processes to the frame or packet. For example, when a LAN switch receives a frame in an interface in VLAN 3, the switch makes a forwarding decision based on the VLAN 3 entries in the MAC address table, and forwards the packet. All this logic focuses on forwarding the user's data, so it is part of a switch's data plane processing.

The term *control plane* refers to the overhead processes that control the work done by the network device, but does not directly impact the forwarding of individual frames or packets. For example, Spanning Tree Protocol (STP) and any IP routing protocol are examples of control plane processes.

Also, some control plane processes do not even indirectly change how the device forwards data. For example, Cisco Discovery Protocol (CDP) can be useful for confirming the accuracy of network documentation, but CDP can be disabled with no effect on the data plane forwarding processes. CDP would also be a control plane process.

To predict the expected operation of a network or to explain the details of how a correctly functioning network is currently working, the person troubleshooting the problem can start with either the control plane or data plane. This text shows the data plane first, but in real life, you can pick one or the other in part based on the known symptoms of the problem.

Data Plane Analysis

Data plane troubleshooting examines, in order, each device in the expected forwarding path for the data. The analysis begins with the host creating the original data. That host sends the data to some other device, which then sends the data to another device, and so on, until the data reaches the endpoint host.

The data plane troubleshooting process should look at both directions of data flowing between two devices. When one device sends data, the receiving host usually sends some sort of reply. So, a problem like "I cannot talk to Server1" may be caused by a problem with packets flowing from the user toward Server1. However, the problem might instead be because of problems with the packets flowing from Server1 back to the user. So, to fully understand how useful communications happen, you also need to analyze the reverse process.

Unless a particular problem's symptoms already suggest a specific problem, data plane troubleshooting should begin with an analysis of the Layer 3 data plane. If you start with Layer 3, you can see the major steps in sending and receiving data between two hosts. You can then examine each individual Layer 3 forwarding step more closely, looking at the underlying Layer 1 and 2 details. For example, Figure 3-1 shows the six major IP forwarding (data plane) steps in a small network.

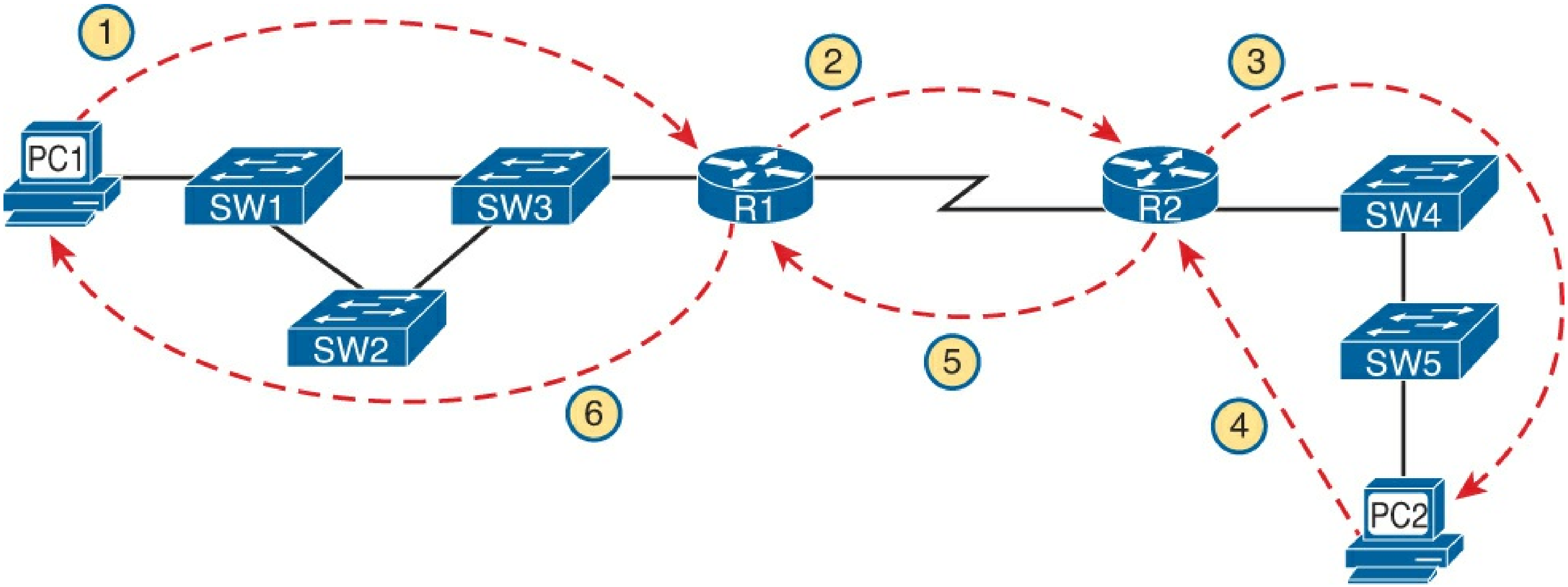


Figure 3-1. Major Steps in an IP Forwarding Example

When trying to understand the expected behavior of Layer 3 in this case, you would need to consider how the packet flows from left to right, and then how the reply flows from right to left. Using the six steps in the figure, the following analysis could be done:

Step 1. Think about PC1's IP address and mask, the IP address and mask of PC2, and PC1's logic to realize that PC2 is in another subnet. This causes PC1 to choose to send the packet to its default gateway (R1).

Step 2. Consider R1's forwarding logic for matching the packet's destination IP address with R1's routing table, with the expectation that R1 chooses to send the packet to R2 next.

Step 3. On R2, consider the same routing table matching logic as used on R1 in the previous step, using R2's routing table. The matching entry should be a connected route on R2.

Step 4. This step relates to PC2's reply packet, which uses the same basic logic as Step 1. Compare PC2's IP address/mask with PC1's IP address, noting that they are in different subnets. As a result, PC2 should send the packet to its default gateway, R2.

Step 5. Consider R2's forwarding logic for packets destined to PC1's IP address, with the expectation that the matching route would cause R2 to send these packets to R1 next.

Step 6. The final routing step, on R1, should show that a packet destined to PC1's IP address matches a connected route on R1, which causes R1 to send the packet directly to PC1's MAC address.

After you have a good grasp of the expected behaviors of each step at Layer 3, you could then more closely examine Layer 2. Following the same ordering again, you could take a closer look at the first Layer 3 routing step in Figure 3-1 (PC1 sending a packet to R1), examining the Layer 1 and 2 details of how the frame is sent by PC1 to be delivered to R1, as shown in Figure 3-2.

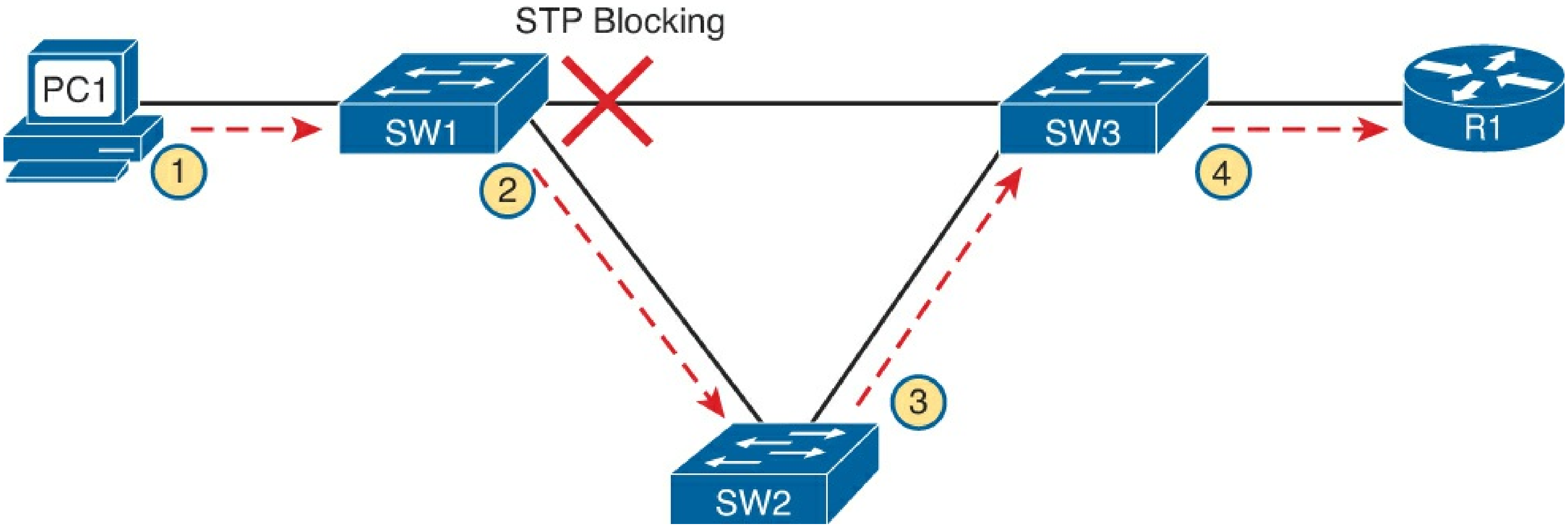


Figure 3-2. Major Steps in a LAN Switching Forwarding Example

For this analysis, you again begin with PC1, this time considering the Ethernet header and trailer, particularly the source and destination MAC addresses. Then, at Step 2, you consider SW1's forwarding logic, which compares the frame's destination MAC address to SW1's MAC address table, telling SW1 to forward the frame to SW2. Steps 3 and 4 repeat Step 2's logic from SW2 and SW3, respectively.

Control Plane Analysis

Many control plane processes directly affect the data plane process. For example, the data plane process of IP routing cannot work without appropriate IP routes, so routers usually use a dynamic routing protocol—a control plane protocol—to learn the routes. Routing protocols are considered to be control plane protocols in part because the work done by a routing protocol does not play a direct role in forwarding a frame or packet.

Although the data plane processes lend themselves to a somewhat generic troubleshooting process of examining the forwarding logic at each device, control plane processes differ too much to allow such generalized troubleshooting. Each control plane process can be examined separately. For example, Chapter 2, "Spanning Tree Protocol Implementation," explains how to approach troubleshooting various types of STP problems.

Predicting Normal Operations: Summary of the Process

On the exams, some questions simply require that you analyze and predict the normal operation of a working network. In other cases, predicting the normal behavior is just a precursor to isolating and fixing a problem. Regardless, if the question gives you no specific clues about the part of the network on which to focus, the following list summarizes a suggested approach for finding the answers:

Step 1. Examine the data plane as follows:

- **A.** Determine the major Layer 3 steps—including origin host to default router, each router to the next router, and last router to the destination host—in both directions.
- **B.** For each Layer 2 network between a host and router or between two routers, analyze the forwarding logic for each device.

Step 2. Examine the control plane as follows:

- **A.** Identify the control plane protocols that are used and vital to the forwarding process.
- **B.** Examine each vital control plane protocol for proper operation; the details of this analysis differ for each protocol.
- **C.** Defer any analysis of control plane protocols that do not affect the data plane's correct operation until you clearly see a need for the protocol to answer that question (for example, CDP).

Problem Isolation

Troubleshooting requires that you find the root cause of the problem and then fix it. The process to find the root cause begins with problem isolation. Problem isolation moves you from the general ideas about a problem, to a specific idea of what the problem is, as follows:

Before problem isolation: I have no idea, except for some general symptoms.

After problem isolation: I have an idea of what is not working, a comparison to how it should be working, and I know on which devices it should be working differently.

For example, consider Figure 3-1 again, which shows a packet being delivered from PC1 to PC2, and back, in six routing steps. In this case, however, you determine that R2 gets the packet that flows left to right in the figure, but the packet is never delivered to PC2. So, you take closer look at the third routing step in the figure, between R2 and PC2, to further isolate the problem. That process of narrowing down the reason for the problem is called *problem isolation*.

After you isolate the problem to one IP forwarding step (as shown in Figure 3-1), you should continue to further isolate the problem to as small a number of components as possible. For example, if R2 gets the packet, but PC2 does not, the problem might be in R2, SW4, SW5, PC2, the cabling, or possibly in devices left out of the network documentation.

The process to further isolate the problem typically requires thinking about functions at many layers of the OSI model and about both data plane and control plane functions. For instance, R2 needs to know PC2's MAC address as learned using Address Resolution Protocol (ARP). If you discover that R2 does not have an ARP entry to PC2, you might be tempted to think that some sort of IP-related problem exists. However, the root cause might be any of these:

- The SW4–SW5 trunk might be shut down.
- The SW5-PC2 cable might be bad.
- The PC2 IPv4 configuration may not have set PC2's IP address.
- The Dynamic Host Configuration Protocol (DHCP) server might be misconfigured, so PC2 did not learn a DHCP address.

Problem isolation refers to the process of starting with a general idea, and getting more and more specific. In the example, that problem was isolated to the point where it was clear that R2's ARP Request for PC2 failed, but as described, the specific reason why the ARP failed had not yet been determined.

If an exam question gives no hints as to where to start, the following process summarizes a good general systematic problem isolation strategy:

Step 1. Begin by examining the Layer 3 data plane (IP forwarding), comparing the results to the expected normal behavior until you identify the first major routing step that fails.

Step 2. Further isolate the problem to as few components as possible:

- **A.** Examine functions at all layers, but focusing on Layers 1, 2, and 3.
- **B.** Examine both data plane and control plane functions.

On the exams, remember that you get no style points for good troubleshooting methods, so just find the answer any way you can, even if that means you guessed a bit based on the context of the question. For example, the suggested process in Step 2A says to focus on Layers 1, 2, and 3; that suggestion is based on the fact that the CCNA exams focus mainly on these three layers. But you should look to shortcut this process as much as possible based on what the question says.

Root Cause Analysis

The final of the three steps, root cause analysis, strives to finish the troubleshooting process to identify the specific device and function that needs to be fixed. The root cause is a problem in the network, that once it is fixed, solves at least part of the original problem.

Finding the root cause is vitally important because the root cause can be fixed. For example, continuing the same problem with R2 not being able to forward packets to PC2, consider the list of problems identified through problem isolation:

- R2 cannot forward packets to PC2.
- R2 gets no ARP Reply from PC2.
- SW4's interface for the trunk to SW5 is in a down/down state.
- The cable used between SW4 and SW5 uses the wrong cabling pinouts.

All these statements might be true about a particular problem scenario, but only the last item has an obvious actionable solution (replace with a correctly wired cable). Although the other statements are valid, and are important facts to think about during problem isolation, they do not imply the specific action to take to solve the problem. As a result, the root cause analysis step reduces to two simple statements:

Step 1. Continue isolating the problem until you identify the true root cause, which in turn has an obvious solution.

Step 2. If you cannot reduce the problem to its true root cause, isolate the problem as much as possible and change something in the network, which may change the symptoms and help you identify the root cause.

Real World Versus the Exams

On the exam, look for clues as to the general topic for which you need to do some part of the troubleshooting process. For example, if the figure shows a network like the one in Figure 3-1, but all the multiple-choice answers refer to VLANs and STP, start by looking at the LAN environment. Note that you might still want to consider Layers 1 through 3, and both the data and control plane details, to help you find the answers.

Note

This section applies generally to troubleshooting, but it is included only in this chapter because this is the first chapter in the book dedicated to troubleshooting.

The introduction to troubleshooting methods is now ended. Now on to some specifics of how to troubleshoot pretty much all of the LAN switching topics covered in the ICND1 exam.

Troubleshooting the LAN Switching Data Plane

Note

Here are a few study tips to begin the second section of this chapter. Take a break, catch your breath, and get ready. This next major section is long, about as long as the average "Foundation Topics" part of most other chapters. If you need to stop reading before the end of this long section, try to end before beginning the next heading that starts with "Step 1","Step 2," and so on.

The generic troubleshooting strategies explained so far in this chapter suggest beginning with the IP routing process at Layer 3. If the engineer identifies a problem at a particular step in the IP forwarding process, the next step should be to examine that routing step more closely, including looking at the underlying Layer 1 and 2 status. If that routing step happens to flow over a LAN, the details in this section can be used to isolate the problem and find the root cause.

This page begins the second of three major sections in this chapter, with a detailed look at the tools and processes used to troubleshoot the LAN data plane processes at Layers 1 and 2. The rest of this chapter assumes that the root cause is a LAN issue, and not a Layer 3 issue; Chapters 4, "Troubleshooting IPv4 Routing Part I," 5, "Troubleshooting IPv4 Routing Part II," and 11, "Troubleshooting IPv4 Routing Protocols," examine Layer 3 troubleshooting for IPv4. This chapter also makes some references to control plane protocols, specifically Spanning Tree Protocol (STP), but STP has already been well covered in the two previous chapters. So, these sections focus specifically on the LAN switching data plane.

As for organization, this major section has five main topics. The first is a review of the LAN switch forwarding processes, and an introduction to the four major steps in the LAN switching troubleshooting process as suggested in this chapter. The other four topics take each of the four troubleshooting steps and break them down, one step at a time.

An Overview of the Normal LAN Switch Forwarding Process

Chapter 1 of this book reviewed the logic a LAN switch uses when forwarding frames. However, that list described the logic without STP. The following process steps outline that logic, with added notes that focus on the impact of STP on the switch forwarding process:

Step 1. Determine the VLAN in which the frame should be forwarded, as follows:

  A. If the frame arrives on an access interface, use the interface's access VLAN.

  B. If the frame arrives on a trunk interface, use the VLAN listed in the frame's trunking header.

Step 2. If the incoming interface is in an STP learning or forwarding state in that VLAN, add the source MAC address to the MAC address table, with incoming interface and VLAN ID (if not already in the table).

Step 3. If the incoming interface is not in an STP forwarding state in that VLAN, discard the frame.

Step 4. Look for the destination MAC address of the frame in the MAC address table, but only for entries in the VLAN identified at Step 1. If the destination MAC is found or not found, follow these steps:

A. Found: Forward the frame out the only interface listed in the matched address table entry.

B. Not found: Flood the frame out all other access ports in that same VLAN that are in an STP forwarding state and out all trunk ports that list this VLAN as fully supported (active, in the allowed list, not pruned, STP forwarding).

To forward a frame, a switch must first determine in which VLAN the frame should be forwarded (Step 1), learn the source MAC addresses as needed (Step 2), and then choose where to forward the frame. Just to make sure that the process is clear, consider an example using Figure 3-3, in which PC1 sends a frame to its default gateway, R1, with the MAC addresses shown in the figure.

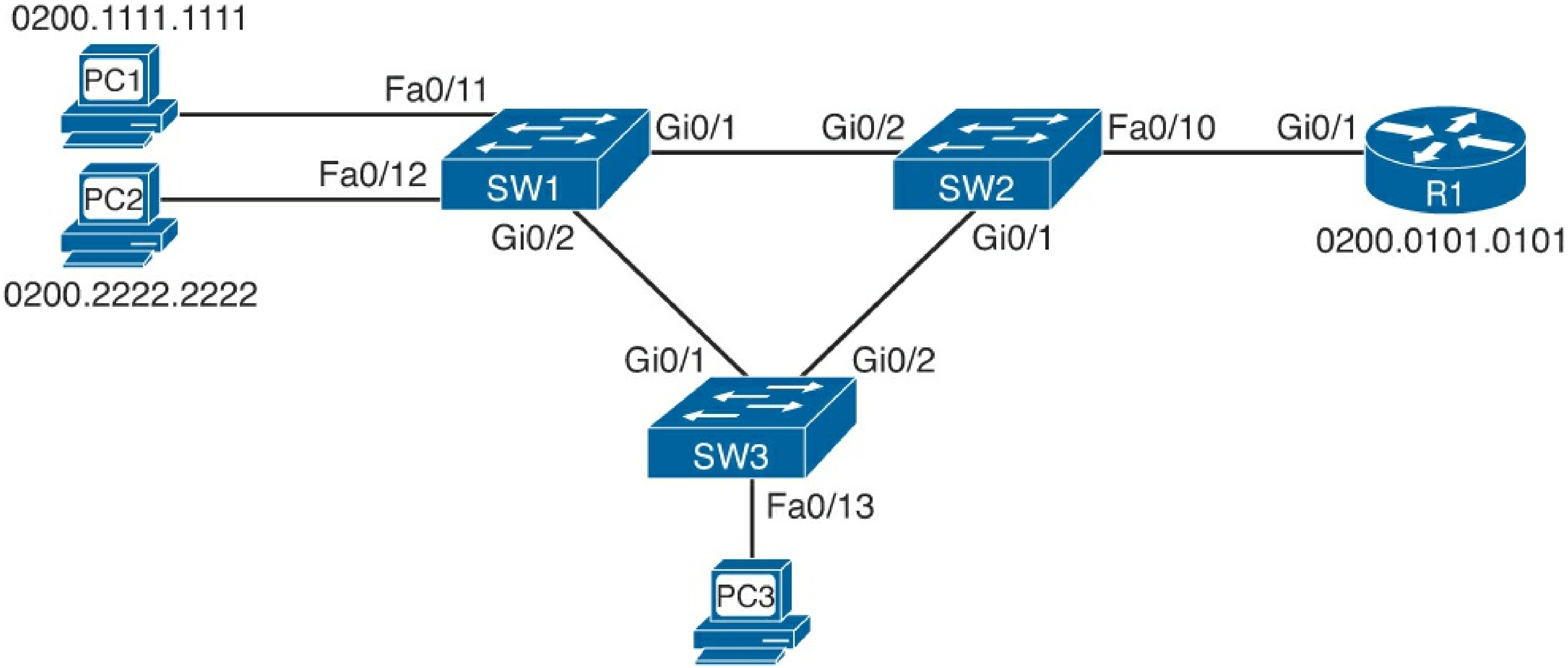


Figure 3-3. Switched Network Used in Data Plane Analysis in Chapter 3

In this case, consider the frame as sent from PC1 (source MAC 0200.1111.1111) to R1 (destination MAC 0200.0101.0101). The following list details the logic at each step of the summary of switching logic:

- SW1, using Step 1, determines whether interface Fa0/11 is operating as an access interface or a trunk. In this case, it is an access interface assigned to VLAN 3.
- For Step 2, SW1 adds an entry to its MAC address table, listing MAC address 0200.1111.1111, interface Fa0/11, and VLAN 3.
- At Step 3, SW1 confirms that the incoming interface, Fa0/11, is in an STP forwarding state.
- Finally, at Step 4, SW1 looks for an entry with MAC address 0200.0101.0101 in VLAN 3. If SW1 finds an entry that lists interface Gigabit 0/1, SW1 then forwards the frame only out Gi0/1. If the outgoing interface (Gi0/1) is a trunk interface, SW1 adds a VLAN trunking header that lists VLAN 3, the VLAN ID determined at Step 1.

For another slightly different example, consider a broadcast sent by PC1. Steps 1 through 3 occur as in this list, but at Step 4, SW1 floods the frame. However, SW1 only floods the frame out access ports in VLAN 3 and trunk ports that support VLAN 3, with the restriction that SW1 will not forward a copy of the frame out ports not in an STP forwarding state.

Although this forwarding logic is relatively simple, the troubleshooting process requires the application of most every LAN-related concept in both the ICND1 and ICND2 books, plus other topics as well. For example, knowing that PC1 first sends frames to SW1, it makes sense to check the interface's status, ensure that the interface is "up and up," and fix the problem with the interface if it is not. Dozens of individual items might need to be checked to troubleshoot a problem. So, this chapter suggests a LAN data plane troubleshooting process that organizes the actions into four main steps:

Step 1. Confirm the network diagrams using CDP.

Step 2. Isolate interface problems.

Step 3. Isolate filtering and port security problems.

Step 4. Isolate VLANs and trunking problems.

The next four sections review and explain the concepts and tools to perform each of these four steps. Although some facts and information are new, most of the specific underlying concepts have already been covered, either in *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide* or in Chapters 1 and 2 of this book. The main goal is to help you pull all the concepts together so that analyzing unique scenarios—as will be required on the exams—takes a little less time, with a much better chance for success.

Step 1: Confirm the Network Diagrams Using CDP

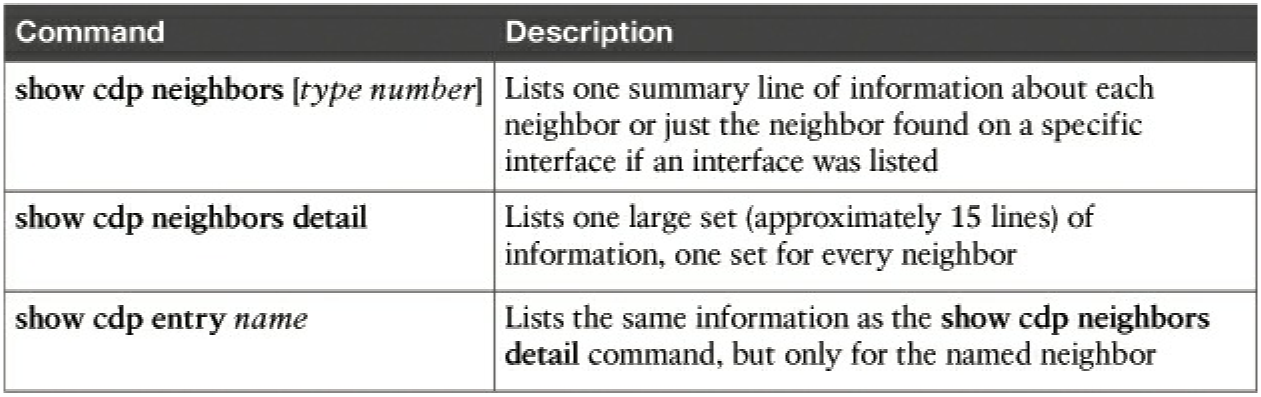
The Cisco Discovery Protocol (CDP) help you verify the information in the network diagram and to complete the rest of the necessary information about the devices and topology. In real life, the network diagrams can be old and outdated, and a problem might be caused because someone moved some cables and did not update the diagrams. I doubt that Cisco would write a question with purposefully inaccurate information in the figure, but the exam might easily include questions for which the network diagram does not list all the required information, and you need to use CDP to find the rest of the details. So, this section reviews CDP, and a good first LAN data plane troubleshooting step is as follows:

Step 1. Verify the accuracy of and complete the information listed in the network diagram using CDP.

> **Note**
>
> This chapter shows a series of numbered troubleshooting steps for LAN switching, begun here with Step 1. The steps and their numbers are unimportant for the exam; the steps are just numbered in this chapter for easier reference.

Cisco routers, switches, and other devices use CDP for a variety of reasons, but routers and switches use it to announce basic information about themselves to their neighbors—information like the hostname, device type, IOS version, and interface numbers. Three commands in particular list the CDP information learned from neighbors, as listed in Table 3-1. In fact, in cases for which no diagram exists, an engineer could create a diagram of routers and switches using **show cdp** command output.

Table 3-1. show cdp **Commands That List Information About Neighbors**



Command	Description
show cdp neighbors [*type number*]	Lists one summary line of information about each neighbor or just the neighbor found on a specific interface if an interface was listed
show cdp neighbors detail	Lists one large set (approximately 15 lines) of information, one set for every neighbor
show cdp entry *name*	Lists the same information as the **show cdp neighbors detail** command, but only for the named neighbor

CDP output can be a little tricky because it may not be obvious whether a listed interface is on the local device, or on a neighbor. Reading left to right, the output usually lists the hostname of the neighboring device under the heading Device ID. However, the next heading of Local Intrfce, meaning local interface, is the local device's interface name/number. The neighboring device's interface name/number is on the right side of the command output under the heading Port ID.

Example 3-1 lists an example **show cdp neighbors** command from SW2 in Figure 3-3. Take the time to compare the shaded portions of the command output to the accurate details in Figure 3-3 to see which fields list interfaces for which devices.

Example 3-1. show cdp **Command Example**

Click here to view code image

```
SW2# show cdp neighbors
Capability Codes: R - Router, T - Trans Bridge, B - Source Route Bridge
S - Switch, H - Host, I - IGMP, r - Repeater, P - Phone,
D - Remote, C - CVTA, M - Two-port Mac Relay

Device ID Local Intrfce Holdtme Capability Platform Port ID
SW1 Gig 0/2 154 S I WS-C2960- Gig 0/1
SW3 Gig 0/1 170 S I WS-C2960- Gig 0/2
R1 Fas 0/10 134 R S I CISCO2901 Gig 0/1
```

CDP creates a security exposure when enabled. To avoid the exposure of allowing an attacker to learn details about each switch, you can easily disable CDP. Cisco recommends that CDP be disabled on all interfaces that do not have a specific need for it. The most likely interfaces that need to use CDP are interfaces connected to other Cisco routers and switches and interfaces connected to Cisco IP phones. Otherwise, CDP can be disabled per interface using the **no cdp enable** interface subcommand. (The **cdp enable** interface subcommand reenables CDP.) Alternatively, the **no cdp run** global command disables CDP for the entire switch, with the **cdp run** global command reenabling CDP globally.

Step 2: Isolate Interface Problems

A Cisco switch interface must be in a working state before the switch can process frames received on the interface or send frames out the interface. So, a somewhat obvious troubleshooting step should be to examine the state of each interface, specifically those expected to be used when forwarding frames, and verify that the interfaces are up and working.

This section examines the possible interface states on a Cisco IOS–based switch, lists root causes for the nonoperational states, and covers a popular problem that occurs even when the interface appears to be in a working state. The specific tasks for this step can be summarized with the following troubleshooting steps:

Step 2. Check for interface problems as follows:

A. Determine interface status code(s) for each required interface, and if not in a connected or up/up state, resolve the problems until the interface reaches the connected or up/up state.

B. For interfaces in a connected (up/up) state, also check for two other problems: duplex mismatches and some variations of port security purposefully dropping frames.

Interface Status Codes and Reasons for Nonworking States

Cisco switches use two different sets of status codes: one set of two codes (words) that uses the same conventions as do router interface status codes, and another set with a single code (word). Both sets of status codes can determine whether an interface is working.

The switch **show interfaces** and **show interfaces description** commands list the two-code status just like routers. The two codes are named the *line status* and *protocol status*, with the codes generally referring to whether Layer 1 is working and whether Layer 2 is working, respectively. LAN switch interfaces typically show an interface with both codes as "up" or both codes as "down" because all switch interfaces use the same Ethernet data link layer protocols, so the data link layer protocol should never have a problem.

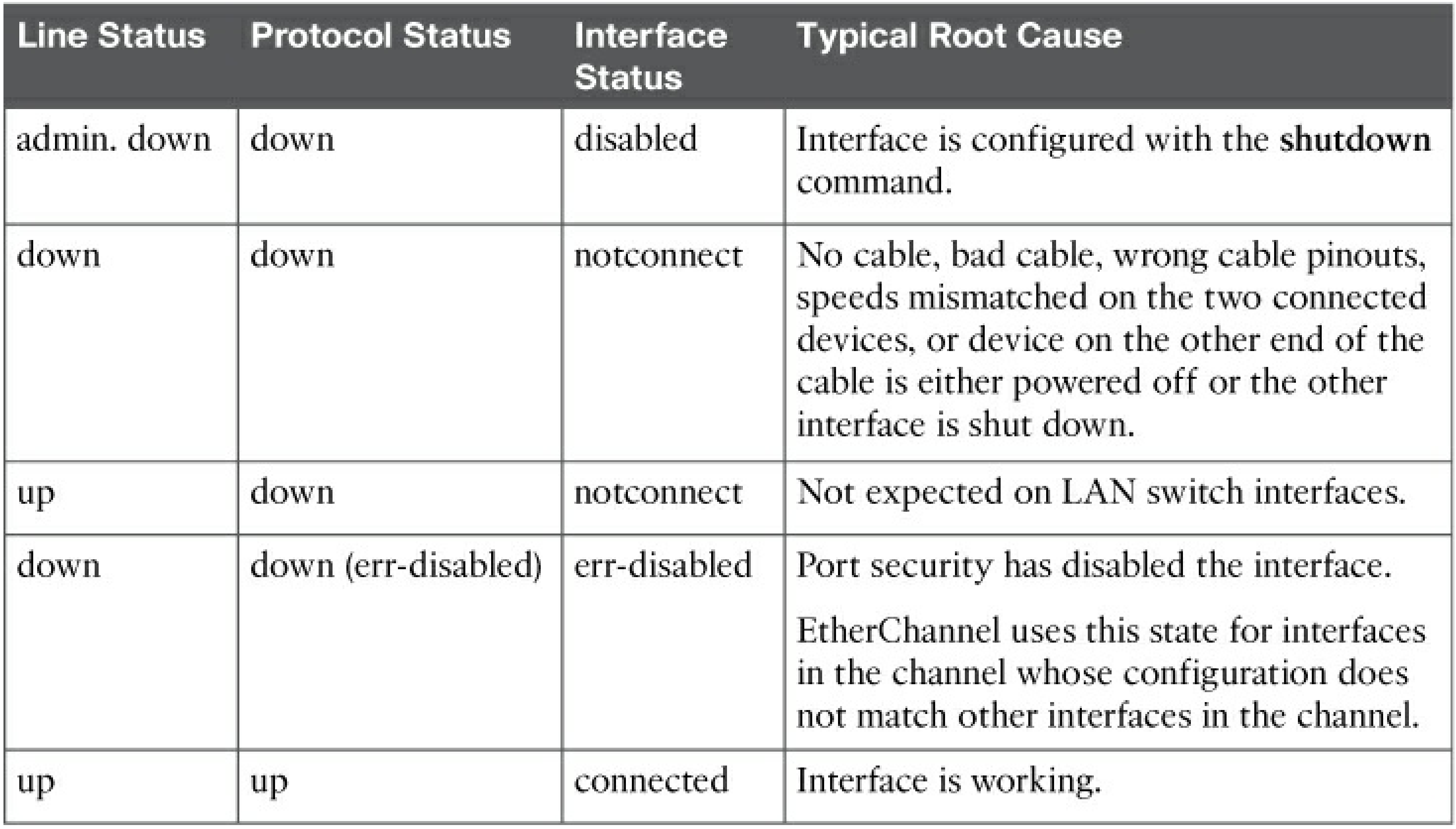
> **Note**
>
> This book refers to these two status codes in shorthand by just listing the two codes with a slash between them (for example, up/up).

The **show interfaces status** command lists a single interface status code. This single interface status code corresponds to different combinations of the traditional two-code interface status codes and can be easily correlated to those codes. For example, the **show interfaces status** command lists a "connected" state for working interfaces, which corresponds to the up/up state seen with the **show interfaces** and **show interfaces description** commands.

Any interface state other than connected and up/up means that the switch cannot forward or receive frames on the interface. Each nonworking interface state has a small set of root causes. Also, note that the exams could easily ask a question that only showed one or the other type of status code, so to be prepared for the exams, know the meanings of both sets of interface status codes. Table 3-2 lists the code combinations and some root causes that could have caused a particular interface status.

Key Topic

Table 3-2. LAN Switch Interface Status Codes



Line Status	Protocol Status	Interface Status	Typical Root Cause
admin. down	down	disabled	Interface is configured with the **shutdown** command.
down	down	notconnect	No cable, bad cable, wrong cable pinouts, speeds mismatched on the two connected devices, or device on the other end of the cable is either powered off or the other interface is shut down.
up	down	notconnect	Not expected on LAN switch interfaces.
down	down (err-disabled)	err-disabled	Port security has disabled the interface. EtherChannel uses this state for interfaces in the channel whose configuration does not match other interfaces in the channel.
up	up	connected	Interface is working.

The notconnect State and Cabling Pinouts

Table 3-2 lists several reasons why a switch interface can be in the notconnect state. Most of those reasons do not need much further explanation than the text in the table. For example, if an interface is connected to another switch, the local switch shows a notconnect state when the other switch's interface has been shut down. However, one of the reasons for a notconnect state—incorrect cable pinouts—deserves a little more attention because it is both a common mistake and is not otherwise covered in this book. (Ethernet cabling pinouts are covered in *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide* Chapter 2.)

Ethernet unshielded twisted-pair (UTP) cabling standards specify the pins to which each of the wires should connect on the RJ-45 connectors on the ends of the cable. The devices transmit using pairs of wires, with 10BASE-T and 100BASE-T using two pairs: one to transmit and one to receive data. When connecting two devices that use the same pair of pins to transmit, the cable—a crossover cable—must connect or cross the wires connected to each device's transmit pair over to the other device's expected receive pair. Conversely, devices that already use opposite pairs for transmitting data need a straight-through cable that does not cross the pairs. Figure 3-4 shows an example in a typical switched LAN, with the types of cabling pinouts shown.

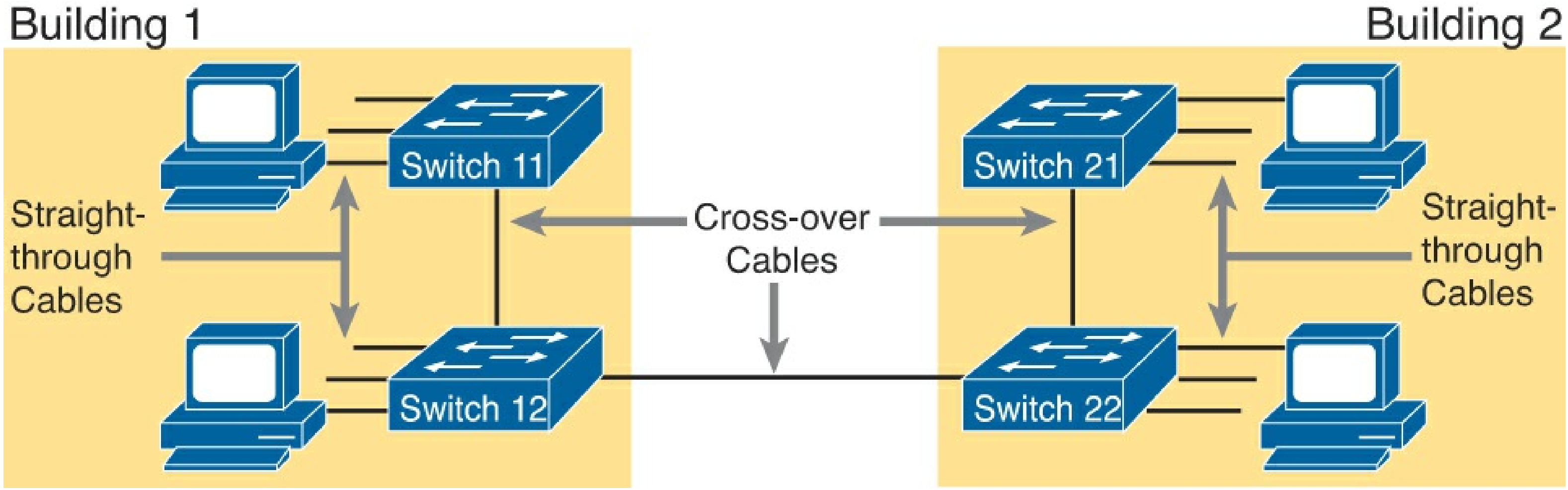
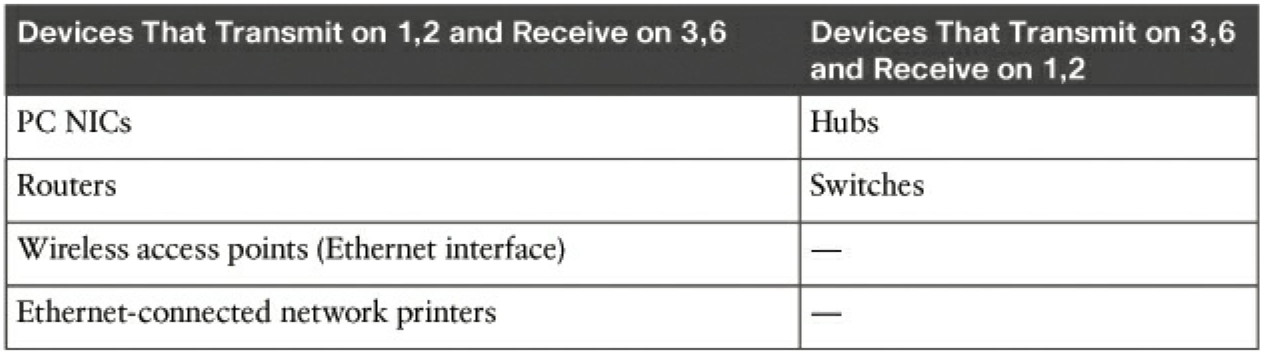


Figure 3-4. Crossover and Straight-Through Cables in Use

Effective troubleshooting requires knowledge of which devices transmit on which pairs. Table 3-3 lists the more common devices seen in the context of CCNA, along with the pairs used. Note that when you are connecting two types of devices from the same column, a crossover cable is required; when you are connecting two devices from different columns of the table, a straight-through cable is required.

Table 3-3. 10BASE-T and 100BASE-T Pin Pairs Used



Devices That Transmit on 1,2 and Receive on 3,6	Devices That Transmit on 3,6 and Receive on 1,2
PC NICs	Hubs
Routers	Switches
Wireless access points (Ethernet interface)	—
Ethernet-connected network printers	—

Determining Switch Interface Speed and Duplex

Switch interfaces can find their speed and duplex settings in several ways. By default, interfaces that use copper wiring use the IEEE-standard autonegotiation process. Alternately, switch interfaces, routers, and most network interface cards (NIC) can also be configured to use a specific speed or duplex setting. On switches and routers, the **speed** {**10** | **100** | **1000**} interface subcommand with the **duplex** {**half** | **full**} interface subcommand sets these values.

The **show interfaces** and **show interfaces status** commands on LAN switches list both the speed and duplex settings on an interface, as shown in Example 3-2.

Example 3-2. Displaying Speed and Duplex Settings on Switch Interfaces

Click here to view code image

```
SW1# show interfaces f0/11 status

Port Name Status Vlan Duplex Speed Type
```

```
Fa0/11 link to PC1 connected 3 a-full 100 10/100BaseTX

SW1# show interfaces f0/12 status

Port Name Status Vlan Duplex Speed Type
Fa0/12 link to PC2 connected 3 a-full a-100 10/100BaseTX

SW1# show interfaces fa0/12
FastEthernet0/12 is up, line protocol is up (connected)
Hardware is Fast Ethernet, address is 1833.9d7b.0e8c (bia 1833.9d7b.0e8c)
Description: link to PC2
MTU 1500 bytes, BW 100000 Kbit/sec, DLY 100 usec,
reliability 255/255, txload 1/255, rxload 1/255
Encapsulation ARPA, loopback not set
Keepalive set (10 sec)
Full-duplex, 100Mb/s, media type is 10/100BaseTX
input flow-control is off, output flow-control is unsupported
ARP type: ARPA, ARP Timeout 04:00:00
Last input never, output 00:00:01, output hang never
Last clearing of "show interface" counters never
Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
Queueing strategy: fifo
Output queue: 0/40 (size/max)
5 minute input rate 0 bits/sec, 0 packets/sec
5 minute output rate 0 bits/sec, 0 packets/sec
1453 packets input, 138334 bytes, 0 no buffer
Received 1418 broadcasts (325 multicasts)
0 runts, 0 giants, 0 throttles
0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored
0 watchdog, 325 multicast, 0 pause input
0 input packets with dribble condition detected
33640 packets output, 2651335 bytes, 0 underruns
0 output errors, 0 collisions, 1 interface resets
0 unknown protocol drops
0 babbles, 0 late collision, 0 deferred
0 lost carrier, 0 no carrier, 0 pause output
0 output buffer failures, 0 output buffers swapped out
```

Although both commands can be useful, only the **show interfaces status** command implies how the switch determined the speed and duplex settings. The command output lists autonegotiated settings with an a-. For example, a-full means full-duplex as autonegotiated, whereas full means full duplex but as manually configured. The example's shaded areas show the following evidence of the use of autonegotiation on F0/11 and F0/12:

F0/11: 100 Mbps due to configuration (100, without an a-), and full duplex due to autonegotiation (a-full)

F0/12: Both values from autonegotiation (both a-100 and a-full with the a-prefix)

Note that the **show interfaces Fa0/12** command (without the **status** option) identifies the speed and duplex but does not state anything about how the switch learned or set the values.

Issues Related to Speed and Duplex

When troubleshooting, and looking at the speed and duplex, looking at the devices on both ends of the link can be helpful. The devices do not have to use the same speed or duplex settings, but with different results, as follows:

Key Topic

- **Speed mismatch:** If the endpoints on an Ethernet link use different speeds, both should show the interface status as notconnect or down/down.
- **Duplex mismatch:** If the endpoints use the same speed, but different duplex settings, the interfaces will come up, but other performance counters will show problems on the half-duplex end of the link.

Interestingly, Cisco switches actually make a speed mismatch difficult to achieve. Clearly, if both devices on the link use autonegotiation, they will choose to use the same speed. However, if the neighboring device disables autonegotiation, a Cisco switch, even without autonegotiation, still figures out the right speed and uses it—unless configured to run at a preset speed with the **speed** command. When configured with a **speed** command, like **speed 100**, the switch interface must attempt to use that speed.

> **Note**
>
> Cisco switches do not have a single command to disable IEEE autonegotiation; however, configuring the

speed and duplex commands to a specific speed and duplex has the side effect of disabling autonegotiation.

For example, in Figure 3-3, imagine that SW2’s Gi0/2 interface were configured with the **speed 100** and **duplex half** commands (not recommended settings on a Gigabit-capable interface, by the way). SW2 would use those settings and disable the IEEE-standard autonegotiation process because both the **speed** and **duplex** commands have been configured. If SW1’s Gi0/1 (on the other end of the link) interface did not have a **speed** command configured, SW1 would still recognize the speed (100 Mbps)—even though SW2 would not use IEEE-standard negotiation—and SW1 would also use a speed of 100 Mbps. Example 3-3 shows the results of this specific case on SW1.

Example 3-3. Displaying Speed and Duplex Settings on Switch Interfaces

Click here to view code image

```
SW1# show interfaces gi0/1 status

Port Name Status Vlan Duplex Speed Type
Gi0/1 Link to SW2 connected trunk a-half a-100 10/100/1000BaseTX
```

The speed and duplex still show up with a prefix of a-in the example, implying autonegotiation. The reason is that, in this case, the speed was found automatically, and the duplex setting was chosen because of the default values used by the IEEE autonegotiation process. The IEEE standards state that if autonegotiation fails for ports running at 100 Mbps, use a default half-duplex setting.

A speed mismatch can be created by simply configuring different speeds on the devices on both ends of the link. Assuming the link was enabled (**no shutdown**), the switch interface would settle to a disabled or down/down state.

Finding a duplex mismatch can be much more difficult than finding a speed mismatch because the switch interface will be in a connected (up/up) state. In this case, the interface works, but it might work poorly, with poor performance and with symptoms of intermittent problems.

A duplex mismatch on a link causes problems because one device (the half-duplex end) uses carrier sense multiple access with collision detection (CSMA/CD) logic, and the other does not. The half-duplex end waits to send if receiving a frame. The half-duplex end believes that when it is sending and another frame starts arriving that a collision has occurred, so the half-duplex end stops sending the frame. The full-duplex end sends frames at any time, causing the half-duplex end to incorrectly believe collisions happen. With enough traffic load, the interface could be in a connected state, but essentially useless for passing traffic, even causing the loss of vital STP messages.

To identify duplex mismatch problems, try the following actions:

Key Topic

- Use commands like **show interfaces** on each end of the link to confirm the duplex setting on each end.
- Watch for increases to certain counters on half-duplex interfaces. The counters—runts, collisions, and late collisions—occur when the other device uses full duplex. (Note that these counters can also increment when legitimate collisions occur as well.)

Example 3-2 (earlier in this section) uses shading to indicate these counters in the output of the **show interfaces** command.

The root cause of duplex mismatches might be related to the defaults chosen by the IEEE autonegotiation process. When a device attempts autonegotiation and the other device does not respond, the first device chooses the default duplex setting based on the current speed. The default duplex settings, per the IEEE, are chosen as follows:

Key Topic

- If the speed is 10 Mbps or 100 Mbps, default to use half duplex.
- If the speed is 1000 Mbps, default to use full duplex.

Note

Ethernet interfaces using speeds faster than 1 Gbps always use full duplex.

Step 3: Isolate Filtering and Port Security Problems

Generally speaking, any analysis of the forwarding process should consider any security features that might discard some frames or packets. For example, both routers and switches can be configured with access control lists (ACL) that examine the packets and frames being sent or received on an interface, with the router or switch discarding those packets/frames.

The CCNA exams do not include coverage of switch ACLs, but the exams do cover a switch feature called port security. As covered in *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*, Chapter 8, the port security feature can be used to cause the switch to discard some frames sent into and out of an interface. Port security has three basic features with which it determines which frames to filter:

- Limit which specific MAC addresses can send and receive frames on a switch interface, discarding frames to/from other MAC addresses
- Limit the number of MAC addresses using the interface, discarding frames to/from MAC addresses learned after the maximum limit is reached
- A combination of the previous two points

The first port security troubleshooting step should be to find which interfaces have port security enabled, followed by a determination as to whether any violations are currently occurring. The trickiest part relates to the differences in what the IOS does in reaction to violations based on the **switchport port-security violation** *violation-mode* interface subcommand, which tells the switch what to do when a violation occurs. The general process is as follows:

Step 3. Check for port security problems as follows:

  A. Identify all interfaces on which port security is enabled (**show running-config** or **show port-security**).

  B. Determine whether a security violation is currently occurring based in part on the *violation mode* of the interface's port security configuration, as follows:

    i. shutdown: The interface will be in an err-disabled state.

    ii. restrict: The interface will be in a connected state, but the **show port-security interface** command will show an incrementing violations counter.

    iii. protect: The interface will be in a connected state, and the **show port-security interface** command will not show an incrementing violations counter.

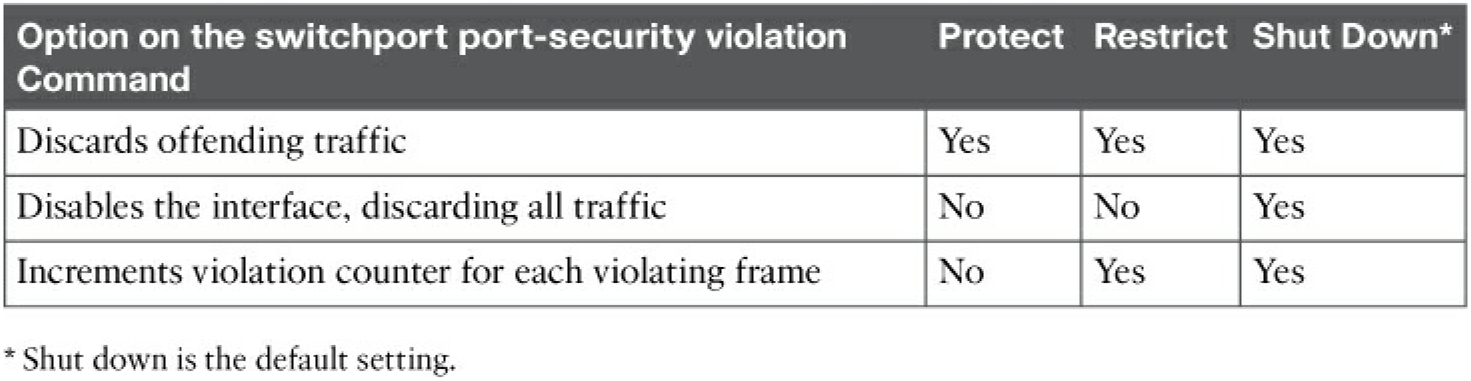
  C. In all cases, compare the port security configuration to the diagram and to the Last Source Address field in the output of the **show port-security interface** command.

One of the difficulties when troubleshooting port security relates to the fact that some port security configurations discard only the offending frames but they do not disable the interface as a result, all based on the configured violation mode. All three violation modes discard the traffic as dictated by the configuration.

For example, if only one predefined MAC address of 0200.1111.1111 is allowed, the switch discards all traffic on that interface, other than traffic to or from 0200.1111.1111. However, "shutdown" mode causes all future traffic to be discarded—even legitimate traffic from address 0200.1111.1111—after a violation has occurred. Table 3-4 summarizes some of these key points for easier study.

Key Topic

Table 3-4. Actions When Port Security Violation Occurs, Based on Mode



Option on the switchport port-security violation Command	Protect	Restrict	Shut Down*
Discards offending traffic	Yes	Yes	Yes
Disables the interface, discarding all traffic	No	No	Yes
Increments violation counter for each violating frame	No	Yes	Yes

* Shut down is the default setting.

Troubleshooting Step 3b refers to the interface err-disabled (error-disabled) state. This state verifies that the interface has been configured to use port security, that a violation has occurred, and that no traffic is allowed on the interface at the present time. This interface state implies that the shutdown violation mode is used, because it is the only one of the three port security modes that causes the interface to be disabled.

To recover from an err-disabled state, the interface must be shut down with the **shutdown** command, and then enabled with the **no shutdown** command. Example 3-4 lists an example in which the interface is in an err-disabled state.

Example 3-4. Using Port Security to Define Correct MAC Addresses of Particular Interfaces

Click here to view code image

```
! The first command lists all interfaces on which port security has been enabled,
! and the violation mode, under the heading "Security Action".
SW1# show port-security
Secure Port MaxSecureAddr CurrentAddr SecurityViolation Security Action
(Count) (Count) (Count)
---------------------------------------------------------------------------
Fa0/13 1 1 1 Shutdown
```

```
---------------------------------------------------------------------------
Total Addresses in System (excluding one mac per port) : 0
Max Addresses limit in System (excluding one mac per port) : 8192

!
! The next command shows the err-disabled state, implying a security violation.
SW1# show interfaces Fa0/13 status

Port Name Status Vlan Duplex Speed Type
Fa0/13 err-disabled 1 auto auto 10/100BaseTX
!
! The next command's output has shading for several of the most important facts.
SW1# show port-security interface Fa0/13
Port Security : Enabled
Port Status : Secure-shutdown
Violation Mode : Shutdown
Aging Time : 0 mins
Aging Type : Absolute
SecureStatic Address Aging : Disabled
Maximum MAC Addresses : 1
Total MAC Addresses : 1
Configured MAC Addresses : 1
Sticky MAC Addresses : 0
Last Source Address:Vlan : 0200.3333.3333:2
Security Violation Count : 1
```

The output of the **show port-security interface** command lists a couple of items helpful in the troubleshooting process. The port status of secure-shutdown means that the interface is disabled for all traffic as a result of a violation, and that the interface state should be err-disabled. The end of the command output lists a violations counter, incremented by 1 for each new violation. Interestingly, with a violation mode of shutdown, the counter increments by 1, the interface is placed into err-disabled state, and the counter cannot increment anymore until the engineer uses the **shutdown** and **no shutdown** commands on the interface, in succession.

Finally, note that the second-to-last line lists the source MAC address of the last frame received on the interface. This value can prove useful in identifying the MAC address of the device that caused the violation.

Moving on to another example, the restrict and protect violation modes still cause frame discards, but with much different behavior. With these violation modes, the interface remains in a connected (up/up) state while still discarding the inappropriate frames because of port security. So, avoid the pitfall of assuming that an interface in a connected, or up/up, state cannot have any other reasons for not passing traffic.

Example 3-5 shows a sample configuration and **show** command when using protect mode. In this case, a PC with MAC address 0200.3333.3333 sent frames into port Fa0/13, with the port configured to restrict Fa0/13 to only receive frames sent by 0200.1111.1111.

Example 3-5. Port Security Using Protect Mode

Click here to view code image

```
SW1# show running-config
! Lines omitted for brevity
interface FastEthernet0/13
switchport mode access
switchport port-security
switchport port-security mac-address 0200.1111.1111
switchport port-security violation protect
! Lines omitted for brevity

SW1# show port-security interface Fa0/13
Port Security : Enabled
Port Status : Secure-up
Violation Mode : Protect
Aging Time : 0 mins
Aging Type : Absolute
SecureStatic Address Aging : Disabled
Maximum MAC Addresses : 1
Total MAC Addresses : 1
Configured MAC Addresses : 1
Sticky MAC Addresses : 0
Last Source Address:Vlan : 0200.3333.3333:1
Security Violation Count : 0
```

This **show** command output was gathered after many frames had been sent by a PC with MAC address 0200.3333.3333, with all the frames being discarded by the switch because of port security. The command output shows the disallowed PC's 0200.3333.3333 MAC address as the last source MAC address in a received frame. However, note that the port status is listed as secure-up and the violation count as 0—both indications that might make you think all is well. However, in protect mode, the **show port-security interface** command does not show any information confirming that an actual violation has occurred. The only indication is that end-user traffic does not make it to where it needs to go.

If this example had used violation mode restrict, the port status would have also stayed in a secure-up state, but the security violation counter would have incremented once for each violating frame.

For the exams, a port security violation might not be a problem; it might be the exact function intended. The question text might well explicitly state what port security should be doing. In these cases, it can be quicker to just immediately look at the port security configuration. Then, compare the configuration to the MAC addresses of the devices connected to the interface. The most likely problem on the exams is that the MAC addresses have been misconfigured or that the maximum number of MAC addresses has been set too low.

The following list summarizes the port security configuration steps, repeated from Chapter 8 of the ICND1 book, for reference:

Step 1. Make the switch interface either a static access or trunk interface, using the **switchport mode access** or the **switchport mode trunk** interface subcommands, respectively.

Step 2. Enable port security using the **switchport port-security** interface subcommand.

Step 3. (Optional) Override the default maximum number of allowed MAC addresses associated with the interface (1) by using the **switchport port-security maximum** *number* interface subcommand.

Step 4. (Optional) Override the default action to take upon a security violation (shutdown) using the **switchport port-security violation** {**protect** | **restrict** | **shutdown**} interface subcommand.

Step 5. (Optional) Predefine any allowed source MAC addresses for this interface using the **switchport port-security mac-address** *mac-address* command. Use the command multiple times to define more than one MAC address.

Step 6. (Optional) Tell the switch to "sticky learn" dynamically learned MAC addresses with the **switchport port-security mac-address sticky** interface subcommand.

Step 4: Isolate VLAN and Trunking Problems

A switch's forwarding process depends on both the definitions of access VLANs on access interfaces and on VLAN trunks that can pass traffic for many VLANs. In addition, before a switch can forward frames in a particular VLAN, the switch must know about a VLAN, either through configuration or VTP, and the VLAN must be active. The following sections examine some of the tools regarding all these VLAN-related issues. This configuration step includes the following steps:

Step 4. Check VLANs and VLAN trunks as follows:

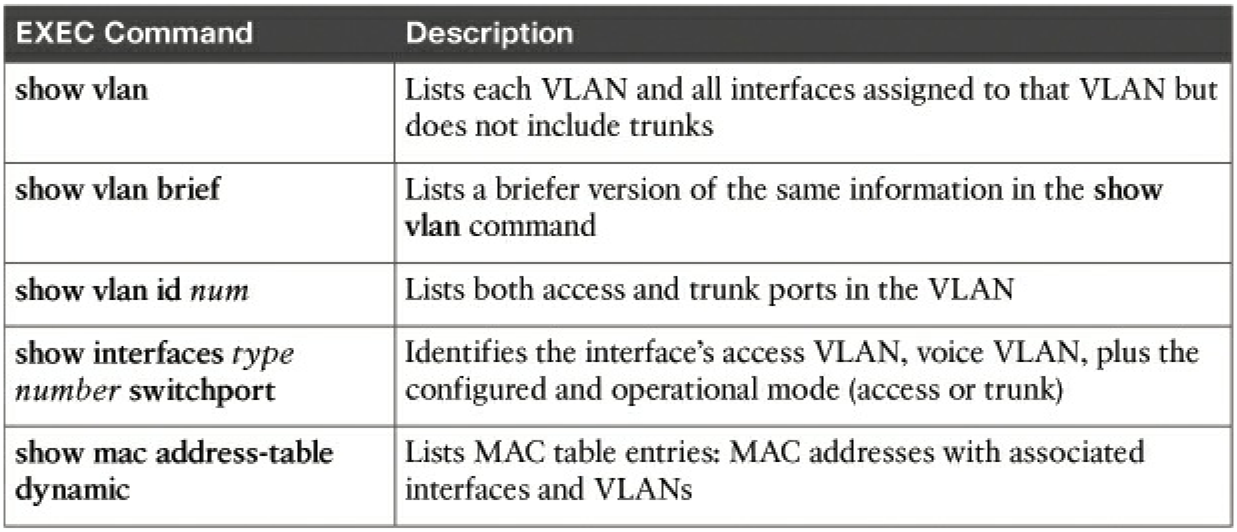
- **A.** Identify all access interfaces and their assigned access VLANs, and reassign into the correct VLANs as needed.
- **B.** Determine whether the VLANs both exist (configured or learned with VTP) and are active on each switch. If not, configure and activate the VLANs to resolve problems as needed.
- **C.** Identify the operationally trunking interfaces on each switch and determine the VLANs that can be forwarded over each trunk.

The next three sections discuss Steps 4A, 4B, and 4C in succession.

Ensuring That the Right Access Interfaces Are in the Right VLANs

To ensure that each access interface has been assigned to the correct VLAN, engineers simply need to determine which switch interfaces are access interfaces instead of trunk interfaces, determine the assigned access VLANs on each interface, and compare the information to the documentation. The **show** commands listed in Table 3-5 can help you with this process.

Table 3-5. Commands That Can Find Access Ports and VLANs



EXEC Command	Description
show vlan	Lists each VLAN and all interfaces assigned to that VLAN but does not include trunks
show vlan brief	Lists a briefer version of the same information in the **show vlan** command
show vlan id *num*	Lists both access and trunk ports in the VLAN
show interfaces *type number* **switchport**	Identifies the interface's access VLAN, voice VLAN, plus the configured and operational mode (access or trunk)
show mac address-table dynamic	Lists MAC table entries: MAC addresses with associated interfaces and VLANs

If possible, start this step with the **show vlan** and **show vlan brief** commands, because they list all the known VLANs and the access interfaces assigned to each VLAN. Be aware, however, that the output of these commands includes many interfaces, but not all; specifically, these commands list the following:

- Interfaces that are not currently operating as trunks
- Interfaces in any current interface state, including those in a notconnect or err-disabled state

For example, these commands might include interface Gi0/2 in the list of interfaces in VLAN 1 when G0/2 is not trunking. However, as soon as Gi0/2 comes up, the interface might negotiate trunking—at which point the interface would no longer be an access interface and would no longer be listed in the output of the **show vlan brief** command.

If the **show vlan** and **show interface switchport** commands are not available in a particular test question, the **show mac address-table** command can also help identify the access VLAN. This command lists the MAC address table, with each entry including a MAC address, interface, and VLAN ID. If the test question implies that a switch interface connects to a single device PC, you should only see one MAC table entry that lists that particular access interface; the VLAN ID listed for that same entry identifies the access VLAN. (You cannot make such assumptions for trunking interfaces.)

After you determine the access interfaces and associated VLANs, if the interface is assigned to the wrong VLAN, use the **switchport access vlan** *vlan-id* interface subcommand to assign the correct VLAN ID.

Access VLANs Not Being Defined or Not Being Active

A switch will not forward a frame in VLAN x if the switch

- Has no definition for VLAN x (for example, with the **vlan** *x* command)
- VLAN x exists on the switch, but it is disabled (**shutdown**)

The next troubleshooting step, Step 4B, is a reminder to make sure each switch has a definition for the VLAN, and that it is not shut down.

Switches normally know of the existence of a VLAN by either learning about the VLAN using VTP or through direct configuration on the local switch. For the purposes of this book, assume that VTP has been disabled or set to use transparent mode. So, for this book, to support a VLAN number x, all switches must be directly configured with the **vlan** *x* command.

Both issues can be easily found from the output of the **show vlan** or **show vlan brief** commands. If the VLAN does not exist on the switch, these commands simply do not list the VLAN; in that case, add the VLAN to the configuration using the **vlan** *vlan-id* configuration command. If listed, the status will be listed as active or act/lshut. The second of these states means that the VLAN is shut down. To solve this problem, use the **no shutdown vlan** *vlan-id* global configuration command.

Identify Trunks and VLANs Forwarded on Those Trunks

At this step (4C), you can separate problems into two general categories as you begin to isolate the problem: problems with the details of how an operational trunk works and problems caused when an interface that should trunk does not trunk.

The first category in this step can be easily done using the **show interfaces trunk** command, which only lists information about currently operational trunks. The best place to begin with this command is the last section of output, which lists the VLANs whose traffic will be forwarded over the trunk. Any VLANs that make it to this final list of VLANs in the command output meet the following criteria:

- The VLAN exists and is active on the local switch (as covered in the previous section and seen in the **show vlan** command).
- The VLAN has not been removed from the allowed VLAN list on the trunk (as configured with the **switchport trunk allowed vlan** interface subcommand).
- The VLAN has not been VTP-pruned from the trunk. (This is a VTP feature, which this section will now otherwise ignore. It is only listed here because the **show** command output mentions it.)
- The trunk is in an STP forwarding state in that VLAN (as also seen in the **show spanning-tree vlan** *vlan-id* command).

Example 3-6 shows a sample of the command output from the **show interfaces trunk** command, with the final section of the command output shaded. In this case, the trunk only forwards traffic in VLANs 1 and 4.

Example 3-6. Allowed VLAN List and List of Active VLANs

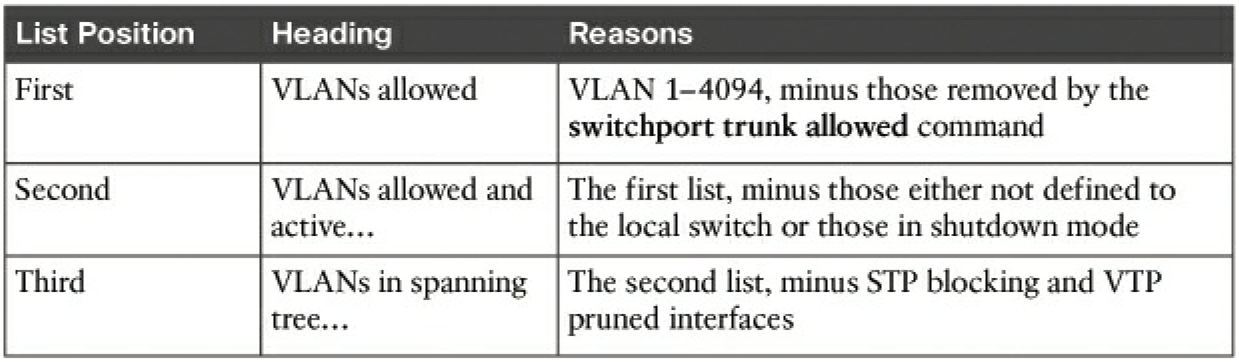
Click here to view code image

```
SW1# show interfaces trunk

Port Mode Encapsulation Status Native vlan
Gi0/1 desirable 802.1q trunking 1

Port Vlans allowed on trunk
Gi0/1 1-2,4-4094

Port Vlans allowed and active in management domain
Gi0/1 1,4

Port Vlans in spanning tree forwarding state and not pruned
Gi0/1 1,4
```

The absence of a VLAN in this last part of the command's output does not necessarily mean that a problem has occurred. In fact, a VLAN might be legitimately excluded from a trunk for any of the reasons in the list just before Example 3-6. However, for a given exam question, it can be useful to know why traffic for a VLAN will not be forwarded over a trunk, and the details inside the output identify the specific reasons.

The output of the **show interfaces trunk** command creates three separate lists of VLANs, each under a separate heading. These three lists show a progression of reasons why a VLAN is not forwarded over a trunk. Table 3-6 summarizes the headings that precede each list and the reasons why a switch chooses to include or not include a VLAN in each list.

Table 3-6. VLAN Lists in the *show interfaces trunk* Command



List Position	Heading	Reasons
First	VLANs allowed	VLAN 1–4094, minus those removed by the **switchport trunk allowed** command
Second	VLANs allowed and active...	The first list, minus those either not defined to the local switch or those in shutdown mode
Third	VLANs in spanning tree...	The second list, minus STP blocking and VTP pruned interfaces

Moving on to another trunking topic, you should also check a trunk's native VLAN configuration at this step. The native VLAN ID can be manually set to different VLANs on either end of the trunk, using the **switchport trunk native vlan** *vlan-id* command. If the native VLANs differ, the switches will accidentally cause frames to leave one VLAN and enter another.

For example, if switch SW1 sends a frame using native VLAN 1 on an 802.1Q trunk, SW1 does not add a VLAN header, as is normal for the native VLAN. When switch SW2 receives the frame, noticing that no 802.1Q header exists, SW2 assumes that the frame is part of SW2's configured native VLAN. If SW2 has been configured to think VLAN 2 is the native VLAN on that trunk, SW2 will try to forward the received frame into VLAN 2.

Finally, check for links that should trunk but that are not trunking. The most likely cause of this problem is a misconfiguration of trunking on the opposite ends of the link. The **switchport mode** {**access** | **trunk** | **dynamic** {**desirable** | **auto**}} interface subcommand tells the interface whether to trunk and the rules with which to negotiate trunking. You can display any interface's administrative (configured) trunking mode, as set by this configuration command, using the **show interface switchport** command.

Make sure that you know the meaning of each of these configuration command's options. The particularly bad combination is to use **dynamic auto** on both ends, which happens to be the default setting on some Cisco switches. This setting on both ends means that both ends will negotiate trunking—if the other end starts the process. So, both ends wait, and never form a trunk. Table 3-7 lists the options on the **switchport trunk mode** command, and what trunking mode that should result.

Table 3-7. Expected Trunking Operational Mode Based on the Configured Administrative Modes

Administrative Mode	Access	Dynamic Auto	Trunk	Dynamic Desirable
access	Access	Access	Access	Access
dynamic auto	Access	Access	Trunk	Trunk
trunk	Access	Trunk	Trunk	Trunk
dynamic desirable	Access	Trunk	Trunk	Trunk

In some cases, an interface can fail to use trunking because of a misconfiguration of the type of trunking—in other words, whether to use Inter-Switch Link (ISL) or 802.1Q. For example, if two switches on opposite ends of a segment configured the **switchport trunk encapsulation isl** and **switchport trunk encapsulation dot1Q** commands, respectively, the trunk would not form, because the types of trunks (the encapsulation) do not match.

Troubleshooting Examples and Exercises

The rest of this chapter is basically practice. It's up to you to decide whether you want to learn by doing more reading, learn by trying to find the answers before reading, or decide that you know how to apply what you read in this chapter and move on to the next chapter.

The rest of this chapter shows two lengthy examples of how to apply troubleshooting concepts and processes to LANs. The first example shows a LAN and lots of **show** commands. The LAN has configuration problems. So, the text uses the four-step process, as described in this chapter, to do problem isolation and uncover the root causes of the problems.

The second example starts with the same LAN as the first problem, with all the problems fixed. In this example, this question is asked: Where do the frames flow in this LAN? This example then examines many **show** commands that prove where the frames will go.

Troubleshooting is a skill, and these examples help you build that skill. One specific skill is to look at a bunch of text in the output of a **show** command and apply what that means to a network diagram. These two examples have 34 **show** commands combined as of the last count. These examples are the last LAN-specific topics in your CCNA study and can help you pull many concepts together. The pieces have probably started to fall into place, and you now understand how much Ethernet LAN technology you have added to your skill set.

Troubleshooting Example 1: Find Existing LAN Data Plane Problems

The first example shows a network diagram, plus a series of examples with **show** command output. The example takes about 12 pages of space in the book. You may use this example in one of two ways:

- **Guided Tour:** Read just like you normally would.
- **Exercise:** Look at the figures and examples, try to find all problems, and develop a plan to fix them. Specifically, look at Figure 3-5. Read Examples 3-7 through 3-14. Ignore the text, and ignore Figure 3-6 at the end of this example. While reading the examples, find as many problems as you can by analyzing the output of the commands, as compared to the figure. Compare your list to the list at the end of the chapter (hidden there to avoid spoiling the answer). Then you can read the text surrounding the examples if you want to fill in the holes in your understanding.

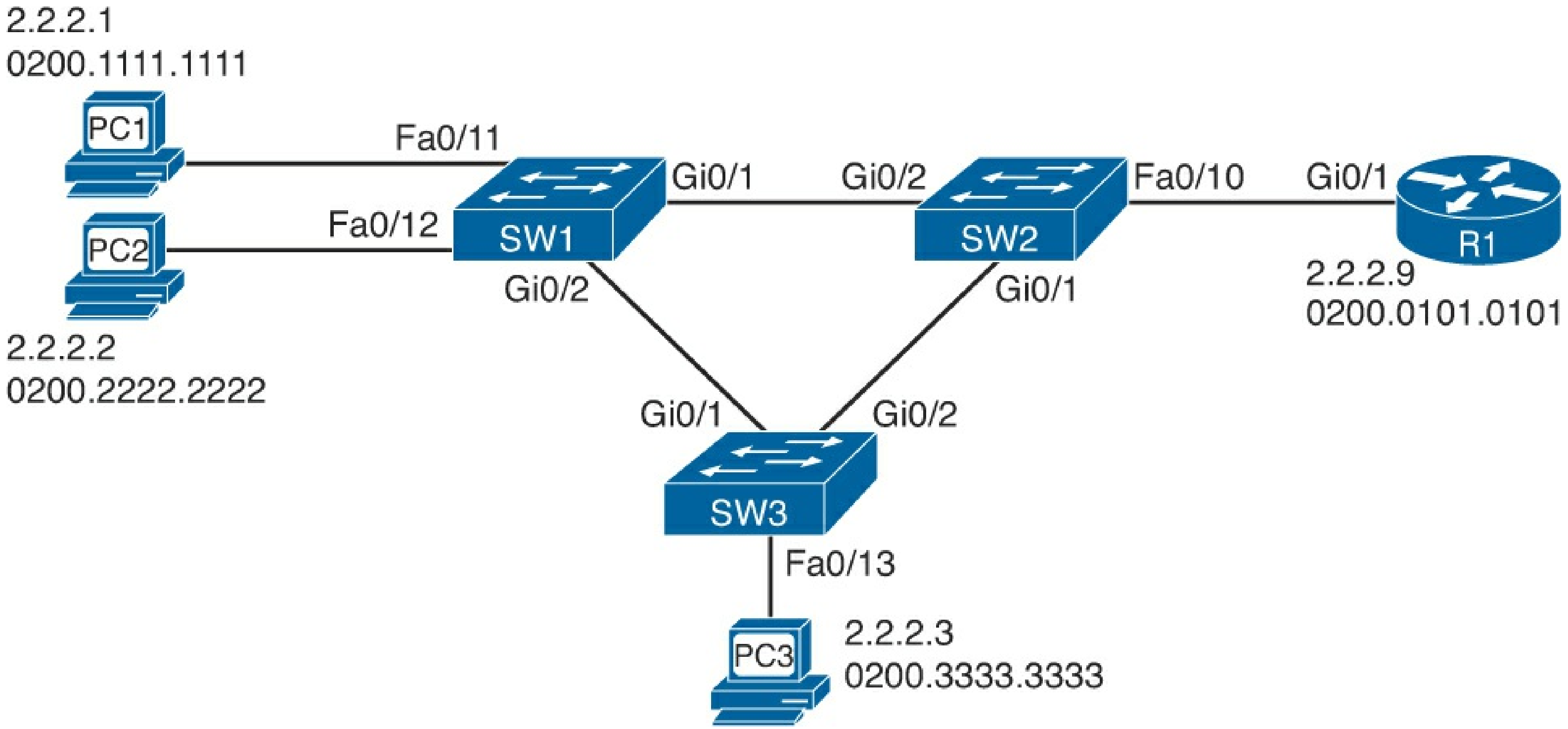


Figure 3-5. Initial Network Diagram for Troubleshooting Example 1

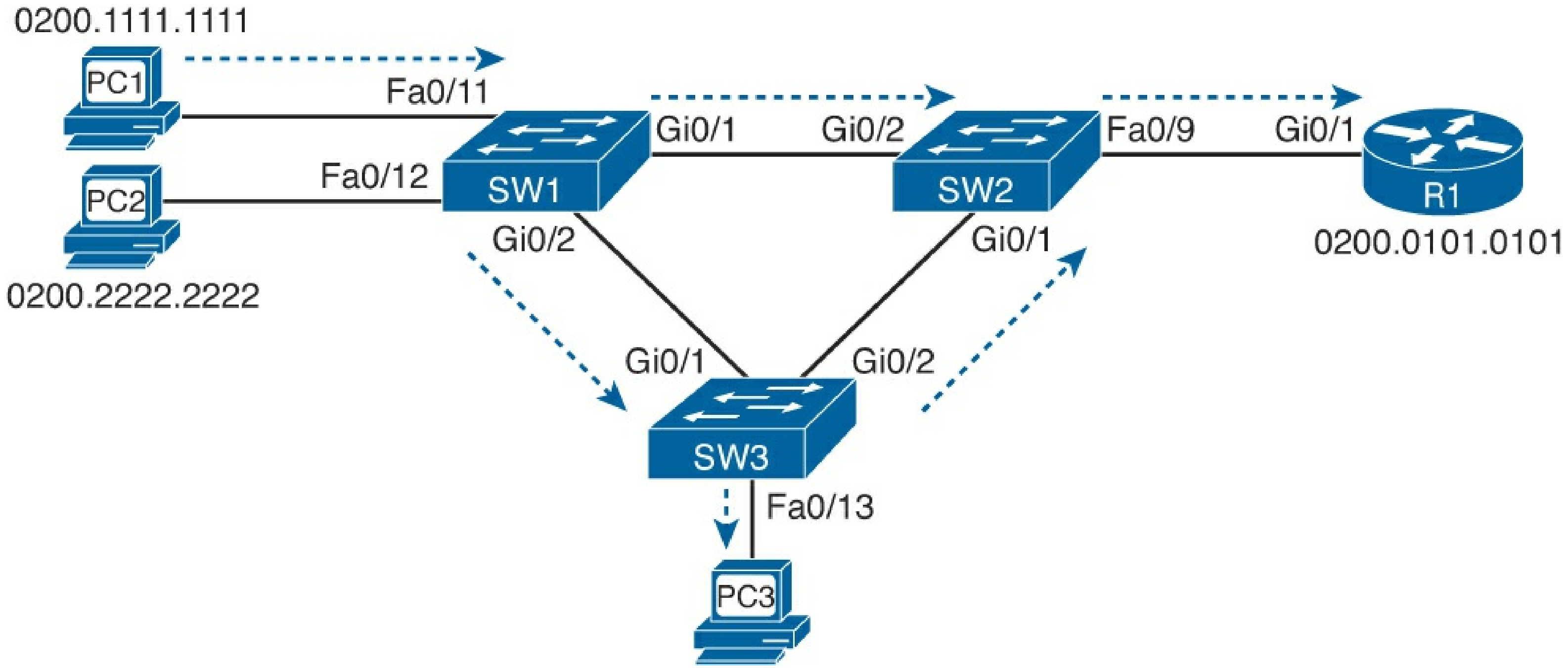


Figure 3-6. Network for Troubleshooting Example 2

This example walks through an examination of the network shown in Figure 3-5, using the output of various **show** commands. The text follows the same four-step process discussed throughout the second major section of this chapter. The beginning of that section summarizes all the troubleshooting steps for reference; to see those steps, refer to the section "An Overview of the Normal LAN Switch Forwarding Process."

For those of you using this troubleshooting example as an exercise, start ignoring the text now and start reading the examples, looking for problems. For those of you using the walkthrough method, keep reading.

Step 1: Verify the Accuracy of the Diagram Using CDP

Example 3-7 shows a variety of example output from the **show cdp neighbors** and **show cdp entry** commands on the three switches in Figure 3-5. A simple comparison confirms the names and interfaces in the figure, with the exception that SW2's Fa0/9 interface connects to Router R1, instead of SW2's Fa0/10 interface shown in Figure 3-5.

Example 3-7. Verifying Figure 3-5 Using CDP

Click here to view code image

```
SW1# show cdp neighbors
Capability Codes: R - Router, T - Trans Bridge, B - Source Route Bridge
S - Switch, H - Host, I - IGMP, r - Repeater, P - Phone,
D - Remote, C - CVTA, M - Two-port Mac Relay

Device ID Local Intrfce Holdtme Capability Platform Port ID
SW2 Gig 0/1 170 S I WS-C2960- Gig 0/2
SW3 Gig 0/2 167 S I WS-C2960- Gig 0/1
```

```
! SW2 commands next
SW2# show cdp neighbors
Capability Codes: R - Router, T - Trans Bridge, B - Source Route Bridge
S - Switch, H - Host, I - IGMP, r - Repeater, P - Phone,
D - Remote, C - CVTA, M - Two-port Mac Relay

Device ID Local Intrfce Holdtme Capability Platform Port ID
SW1 Gig 0/2 146 S I WS-C2960- Gig 0/1
SW3 Gig 0/1 162 S I WS-C2960- Gig 0/2
R1 Fas 0/9 139 R S I CISCO2901 Gig 0/1

SW2# show cdp entry R1

-------------------------
Device ID: R1
Entry address(es):
IP address: 2.2.2.9
```

```
Platform: Cisco CISCO2901/K9, Capabilities: Router Switch IGMP
Interface: FastEthernet0/9, Port ID (outgoing port): GigabitEthernet0/1
Holdtime : 148 sec

Version :
Cisco IOS Software, C2900 Software (C2900-UNIVERSALK9-M), Version 15.2(4)M1, RELEASE SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2012 by Cisco Systems, Inc.
Compiled Thu 26-Jul-12 20:54 by prod_rel_team

advertisement version: 2
VTP Management Domain: ''
Duplex: full
Management address(es):
```

```
! SW3 command next
SW3# show cdp neighbors

Capability Codes: R - Router, T - Trans Bridge, B - Source Route Bridge
S - Switch, H - Host, I - IGMP, r - Repeater, P - Phone,
D - Remote, C - CVTA, M - Two-port Mac Relay

Device ID Local Intrfce Holdtme Capability Platform Port ID
SW1 Gig 0/1 167 S I WS-C2960- Gig 0/2
SW2 Gig 0/2 176 S I WS-C2960- Gig 0/1
```

This mistake in documentation in Figure 3-5 (listing SW2 interface Fa0/10 instead of Fa0/9) may or may not affect the current network's operation. For instance, had trunking been required between SW2 and R1, SW2 interface Fa0/9—not Fa0/10—would have to have been explicitly configured to enable trunking, because routers cannot automatically negotiate to use trunking.

Note that CDP does not identify documentation problems with the interfaces that connect to the end-user PCs; for the purposes of this example, know that the rest of the interfaces shown in Figure 3-5 are the correct interfaces.

Step 2: Check for Interface Problems

The next step examines the interface status on each of the interfaces that should currently be used. Example 3-8 lists several **show interface status** commands on both SW1 and SW3. (For this chapter's purposes, assume that all interfaces on SW2 are working correctly.) Examine the output, identify any problems you see, and make a list of other interface-related problems you might want to investigate further based on this output.

Example 3-8. Interface Problems on SW1 and SW3

Click here to view code image

```
SW1# show interfaces fa0/11 status
Port Name Status Vlan Duplex Speed Type
Fa0/11 connected 3 a-full a-100 10/100BaseTX

SW1# show interfaces fa0/12 status
Port Name Status Vlan Duplex Speed Type
Fa0/12 notconnect 3 auto auto 10/100BaseTX

SW1# show interfaces Gi0/1 status
Port Name Status Vlan Duplex Speed Type
Gi0/1 connected trunk a-full a-1000 10/100/1000BaseTX

SW1# show interfaces Gi0/2 status
Port Name Status Vlan Duplex Speed Type
Gi0/2 connected trunk a-full a-1000 10/100/1000BaseTX
```

```
! Switching to SW3 next
SW3# show interfaces fa0/13 status
Port Name Status Vlan Duplex Speed Type
Fa0/13 connected 3 a-half a-100 10/100BaseTX

SW3# show interfaces Gi0/1 status
Port Name Status Vlan Duplex Speed Type
```

```
Gi0/1 connected trunk a-full a-1000 1000BaseTX

SW3# show interfaces Gi0/2 status
Port Name Status Vlan Duplex Speed Type
Gi0/2 connected trunk a-full a-1000 1000BaseTX
```

One obvious problem exists on SW1, with interface Fa0/12 in a notconnect state. Many reasons for this state exist, almost all relating to some cabling problem—anything from a cable that is not fully inserted into the switch port to difficult-to-find interference problems on the cable. (See Table 3-2 for suggested reasons.)

SW3's interfaces appear not to have any problems. However, all three interfaces have a duplex setting that is the same setting as what the switch would use if the autonegotiation process failed, with the use of half duplex on Fa0/13 being notable. That raises the possibility of a duplex mismatch.

You can determine that SW3's Gigabit 0/1 and 0/2 interfaces do not have a mismatch by simply using the **show interfaces status** command on SW1 and SW2 on the other end of those links, respectively. However, ports connected to a PC pose a troubleshooting problem in that you probably will not be near the PC, so you might have to guide the end user through some steps to verify the speed and duplex settings. However, it is helpful to look for the telltale signs of runts, collisions, and late collisions, as listed in the output of the **show interfaces** command in Example 3-9.

Example 3-9. Signs of a Duplex Mismatch

Click here to view code image

```
SW3# show interfaces fa0/13
FastEthernet0/13 is up, line protocol is up (connected)
Hardware is Fast Ethernet, address is f47f.35cb.d78d (bia f47f.35cb.d78d)
MTU 1500 bytes, BW 100000 Kbit/sec, DLY 100 usec,
reliability 255/255, txload 1/255, rxload 1/255
Encapsulation ARPA, loopback not set
Keepalive set (10 sec)
Half-duplex, 100Mb/s, media type is 10/100BaseTX
input flow-control is off, output flow-control is unsupported
ARP type: ARPA, ARP Timeout 04:00:00
Last input never, output 00:00:01, output hang never
Last clearing of "show interface" counters never
Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
Queueing strategy: fifo
Output queue: 0/40 (size/max)
5 minute input rate 0 bits/sec, 0 packets/sec
5 minute output rate 0 bits/sec, 0 packets/sec
14507 packets input, 1003344 bytes, 0 no buffer
Received 14488 broadcasts (466 multicasts)
54 runts, 0 giants, 0 throttles
0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored
0 watchdog, 466 multicast, 0 pause input
0 input packets with dribble condition detected
43824 packets output, 3440304 bytes, 0 underruns
0 output errors, 114 collisions, 2 interface resets
0 unknown protocol drops
0 babbles, 78 late collision, 0 deferred
0 lost carrier, 0 no carrier, 0 pause output
0 output buffer failures, 0 output buffers swapped out
```

In this case, a duplex mismatch does indeed exist, with the switch port using half duplex. However, note that these same counters do increment under normal half-duplex operations, so these counters do not definitively identify the problem as a duplex mismatch.

In this case, SW3's configuration needs to be changed from half duplex to full duplex on interface Fa0/13, matching the manual setting on PC3.

Step 3: Check for Port Security Problems

The next step examines the port security configuration and status on each switch. Starting with the **show port-security** command is particularly helpful because it lists the interfaces on which the feature has been enabled. Example 3-10 shows this command on SW1 and SW2, plus a few other commands. Note that both SW2 and SW3 do not have the port security feature enabled.

Examine the output in Example 3-10, and before reading beyond the end of the example, make a few notes about what next steps you would take to either rule out port security as a potential problem or what command you would use to further isolate a potential problem.

Example 3-10. Port Security on SW1 and SW2

Click here to view code image

```
SW1# show port-security
Secure Port MaxSecureAddr CurrentAddr SecurityViolation Security Action
(Count) (Count) (Count)
---------------------------------------------------------------------------
Fa0/11 1 1 97 Restrict
---------------------------------------------------------------------------
Total Addresses in System (excluding one mac per port) : 0
Max Addresses limit in System (excluding one mac per port) : 4096
```

```
! On SW2 below, no interfaces have port security enabled.
SW2# show port-security
Secure Port MaxSecureAddr CurrentAddr SecurityViolation Security Action
(Count) (Count) (Count)
---------------------------------------------------------------------------
---------------------------------------------------------------------------
Total Addresses in System (excluding one mac per port) : 0
Max Addresses limit in System (excluding one mac per port) : 8192
```

The **show port-security** commands in the example list the interfaces on which port security has been enabled—specifically, SW1 interface Fa0/11 and no interfaces on SW2. On SW1, the notable items for troubleshooting are that the security action heading, which matches the violation mode setting, shows an action of restrict. With the restrict setting, SW1 interface Fa0/11 can be in the connected state (as seen in Example 3-8), but port security can be discarding traffic that violates the port security configuration. So, a closer examination of the port security configuration is in order, as shown in Example 3-11.

Example 3-11. Port Security on SW1 and SW2

Click here to view code image

```
SW1# show port-security interface fa0/11
Port Security : Enabled
Port Status : Secure-up
Violation Mode : Restrict
Aging Time : 0 mins
Aging Type : Absolute
SecureStatic Address Aging : Disabled
Maximum MAC Addresses : 1
Total MAC Addresses : 1
Configured MAC Addresses : 1
Sticky MAC Addresses : 0
Last Source Address:Vlan : 0200.1111.1111:3
Security Violation Count : 97
!
! Next, the configuration shows that the configured MAC address does not
! match PC1's MAC address.
SW1# show running-config interface fa0/11

interface FastEthernet0/11
switchport access vlan 3
switchport mode access
switchport port-security
switchport port-security violation restrict
switchport port-security mac-address 0200.3333.3333
!
! The following log message also points to a port security issue.
01:46:58: %PORT_SECURITY-2-PSECURE_VIOLATION: Security violation occurred, caused by MAC address 0200.1111.1111
on port FastEthernet0/11.
```

The example begins by confirming the security mode and violation counter and showing the last MAC address (0200.1111.1111) to send a frame into interface Fa0/11. PC1's MAC address (0200.1111.1111) does not match the port security configuration as shown in the second part of the example, a configuration that defaults to a maximum of one MAC address with an explicitly configured MAC address of 0200.3333.3333.

A simple solution is to reconfigure port security to instead list PC1's MAC address. Note that the engineer would not need to use the **shutdown** and then the **no shutdown** commands on this interface to recover the interface, because the configuration uses violation mode restrict, which leaves the interface up while discarding the traffic to/from PC1.

Finally, the end of the example shows a log message generated by the switch for each violation when using restrict mode. This log message would be seen from the console, or from a Telnet or Secure Shell (SSH) connection to the switch, if the remote user had issued the **terminal monitor** EXEC command. It can also be collected at a syslog server, as described in Chapter 19, "Managing Network Devices."

Step 4: Check for VLAN and VLAN Trunk Problems

Step 4A begins by examining the access interfaces to ensure that the interfaces have been assigned to the correct VLANs. In this case, all interfaces connected to PCs and routers in Figure 3-5 should be assigned to VLAN 3. Example 3-12 provides some useful **show** command output. Take a few moments to read through the example and look for any VLAN assignment problems.

Example 3-12. Checking Access Interface VLAN Assignments

Click here to view code image

```
SW1# show interfaces fa0/11 status

Port Name Status Vlan Duplex Speed Type
Fa0/11 connected 3 a-full a-100 10/100BaseTX
SW1# show interfaces fa0/12 status

Port Name Status Vlan Duplex Speed Type
Fa0/12 notconnect 3 auto auto 10/100BaseTX
```

```
! SW2 next
SW2# show interfaces status
! lines omitted for brevity
Fa0/9 connected 1 a-full a-100 10/100BaseTX
Fa0/10 notconnect 3 auto auto 10/100BaseTX
```

```
! SW3 next
SW3# show interfaces fa0/13 status

Port Name Status Vlan Duplex Speed Type
Fa0/13 connected 3 full a-100 10/100BaseTX
```

The only problem in this case is the fact that while SW2's Fa0/10 interface was assigned to VLAN 3, per the drawing in Figure 3-5, SW2 connects to R1 using Fa0/9 (as shown with CDP in Example 3-7). Interface Fa0/9 defaults to be in VLAN 1. To solve this particular problem, on SW2, configure the **switchport access vlan 3** interface subcommand on interface Fa0/9.

The next part of Step 4 (Step 4B) suggests to check the VLANs to ensure that they are active on each switch. This ongoing example only uses VLAN 3, so Example 3-13 shows that VLAN 3 indeed is known on each switch. When reading the example, look for any problems with VLAN 3.

Example 3-13. Checking for Active VLANs

Click here to view code image

```
SW1# show vlan id 3

VLAN Name Status Ports
---- -------------------------------- --------- -------------------------------
3 book-vlan3 active Fa0/11, Fa0/12, Gi0/1, Gi0/2
! lines omitted for brevity
```

```
! SW2 next
SW2# show vlan brief

VLAN Name Status Ports
---- -------------------------------- --------- -------------------------------
1 default active Fa0/1, Fa0/2, Fa0/3, Fa0/4
Fa0/5, Fa0/6, Fa0/7, Fa0/8
Fa0/11, Fa0/12, Fa0/13, Fa0/14
Fa0/15, Fa0/16, Fa0/17, Fa0/18
Fa0/19, Fa0/20, Fa0/21, Fa0/22
```

```
Fa0/23, Fa0/24
3 VLAN0003 active Fa0/9, Fa0/10
! lines omitted for brevity
```

```
! SW3 next
SW3# show vlan brief

VLAN Name Status Ports
---- -------------------------------- --------- -------------------------------
1 default active Fa0/1, Fa0/2, Fa0/3, Fa0/4
Fa0/5, Fa0/6, Fa0/7, Fa0/8
Fa0/9, Fa0/10, Fa0/11, Fa0/12
Fa0/14, Fa0/15, Fa0/16, Fa0/17
Fa0/18, Fa0/19, Fa0/20, Fa0/21
Fa0/22, Fa0/23, Fa0/24
3 book-vlan3 active Fa0/13
! lines omitted for brevity
```

In this case, VLAN 3 exists and is active on all three switches. However, SW2 lists a different name than do the other two switches. The name is unimportant to the operation of the VLAN, so this difference does not matter.

Finally, the last part of troubleshooting Step 4 (Step 4C) suggests that you confirm the trunking status of all expected trunk interfaces. It is also helpful to determine on which trunks the VLANs will be forwarded. Example 3-14 lists output that helps supply the answers. Examine the output in the example, and before reading past the end of the example, list any trunks that do not currently forward traffic in VLAN 3 and make a list of possible reasons why VLAN 3 is omitted from the trunk.

Example 3-14. Verifying Trunking and VLAN 3

Click here to view code image

```
SW1# show interfaces trunk

Port Mode Encapsulation Status Native vlan
Gi0/1 desirable 802.1q trunking 1
Gi0/2 desirable 802.1q trunking 1

Port Vlans allowed on trunk
Gi0/1 1-4094
Gi0/2 1-4094

Port Vlans allowed and active in management domain
Gi0/1 1,3
Gi0/2 1,3

Port Vlans in spanning tree forwarding state and not pruned
Gi0/1 3
Gi0/2 1,3
```

```
! SW2 next
SW2# show interfaces trunk

Port Mode Encapsulation Status Native vlan
Gi0/1 auto 802.1q trunking 1
Gi0/2 auto 802.1q trunking 1

Port Vlans allowed on trunk
Gi0/1 1-4094
Gi0/2 1-4094

Port Vlans allowed and active in management domain
Gi0/1 1,3
Gi0/2 1,3

Port Vlans in spanning tree forwarding state and not pruned
Gi0/1 1,3
Gi0/2 1
```

```
! SW3 next
SW3# show interfaces trunk

Port Mode Encapsulation Status Native vlan
Gi0/1 auto 802.1q trunking 1
Gi0/2 desirable 802.1q trunking 1

Port Vlans allowed on trunk
Gi0/1 1-4094
Gi0/2 1-4094

Port Vlans allowed and active in management domain
Gi0/1 1,3
Gi0/2 1,3

Port Vlans in spanning tree forwarding state and not pruned
Gi0/1 1,3
Gi0/2 1,3
```

First, look at the end of the output for all three commands in the example and focus on VLAN 3. Of the trunk ports on these switches, all list VLAN 3 in their last list of VLANs, with one exception: SW2's G0/2 port. Why? STP chose to block in VLAN 3 on that port.

Several different **show spanning-tree** commands could confirm that SW2's G0/2 port blocks in VLAN 3, but you can also deduce that SW2's G0/2 must be blocking from the output in the example. To do so, just rule out the other reasons as to why VLAN 3 would not be included in the lists in the output of the **show interfaces trunk** command, as follows:

- VLAN 3 is listed in the first list of VLANs from SW2's **show interfaces trunk** command output, meaning that VLAN 3 must be in the allowed list for that trunk.
- VLAN 3 is listed in the second list of VLANs from SW2's **show interfaces trunk** command output, meaning that VLAN 3 is active on SW2.

After finding and fixing all the problems in this ongoing example, PC1, PC3, and R1 can all ping each other. PC2, with an unspecified cabling problem, still does not work.

Troubleshooting Example 2: Predicting LAN Data Plane Behavior

This second example takes a much different approach than the first. Instead of starting with many problems, this example has a completely working LAN. Your job is to analyze the LAN to predict where the data plane will forward frames.

This example actually uses the same LAN as the previous example, but this time, all the errors have been fixed. In this case, the LAN works, and the example focuses on using show commands to predict exactly where frames flow in the LAN. In particular, this example focuses on two messages:

- PC1 sends an ARP Request for Router R1 as a broadcast frame.
- R1 sends an ARP Reply, which is a unicast frame, back to PC1.

Figure 3-6 correctly details the network. Figures 3-7 and 3-8, at the end of this section, show the flow of the ARP Request and Reply, respectively.

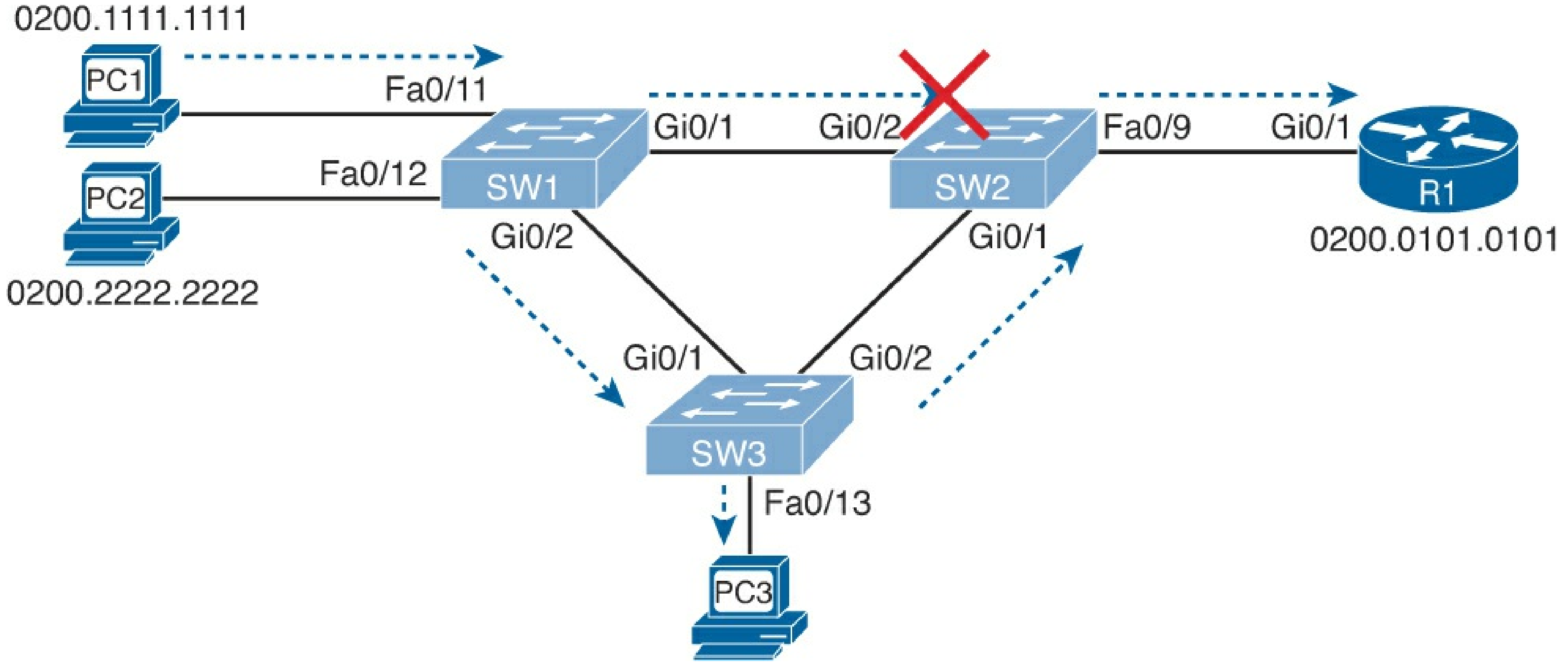


Figure 3-7. Forwarding Path of ARP Broadcast, from PC1 to R1

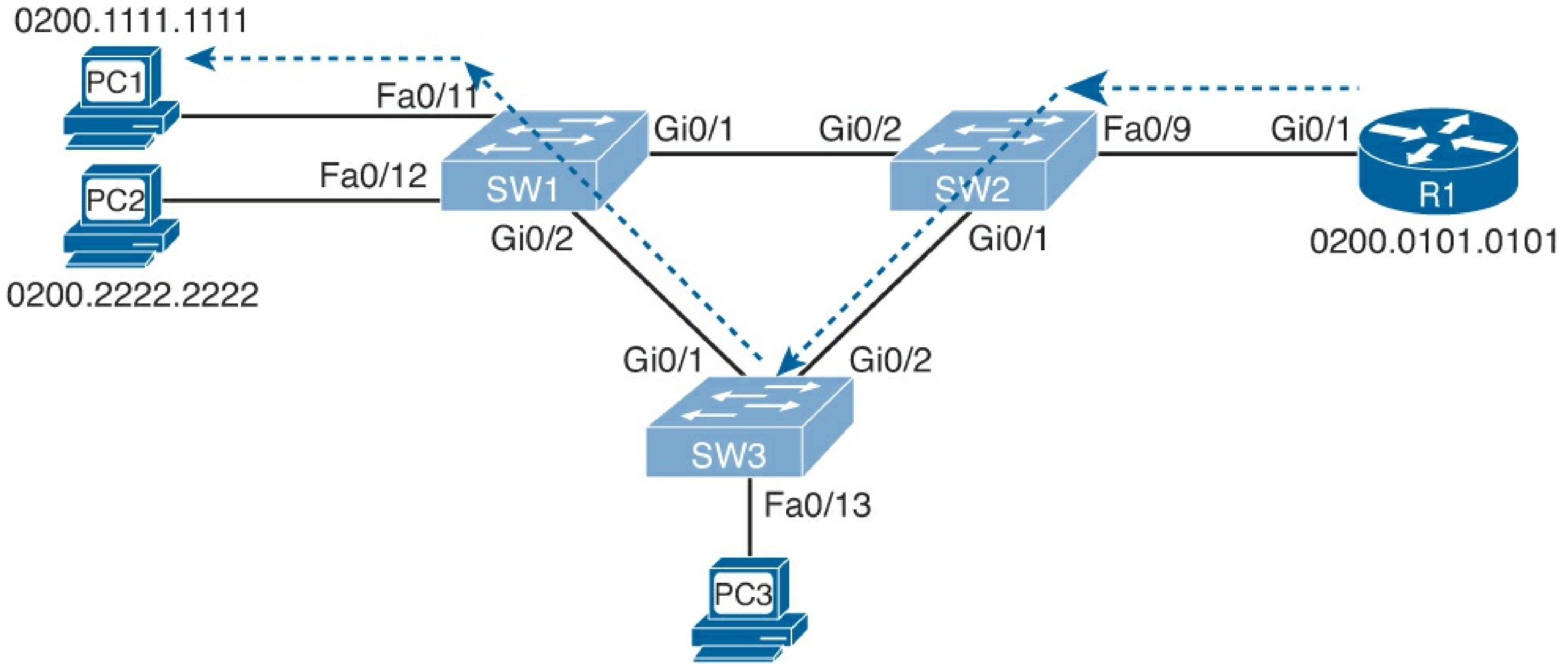


Figure 3-8. Forwarding Path of ARP Reply, From R1 to PC1

> **Note**
>
> The network for this example uses the same design as the previous example, but with the problems fixed. All access ports are in VLAN 3.

For those of you wanting to use this example as a practice exercise, use Figure 3-6; just read the examples and ignore the text between the examples. Make all the notes you can about where PC1's ARP broadcast will flow, and where R1's ARP Reply will flow. If you prefer, just keep reading for a walkthrough of what happens.

PC1 ARP Request (Broadcast)

When PC1 needs to send an IP packet to another subnet, PC1 will want to send the packet to PC1's default router. R1 serves as PC1's default router in this case. If PC1 does not list R1's MAC address in PC1's ARP cache, PC1 sends an ARP broadcast with an Ethernet destination address of FFFF.FFFF.FFFF.

To analyze the flow of the broadcast, see the generic forwarding process, as summarized in the section "An Overview of the Normal LAN Switching Forwarding Process," earlier in this chapter. Earlier examples confirmed that SW1 port Fa0/11 is assigned to VLAN 3 and that SW1's Fa0/11 interface is an access interface. Because the frame is a broadcast, SW1 will flood the frame. So now, Example 3-15 lists enough information to predict the interfaces out which SW1 will forward the broadcast frame sent by PC1 by listing the output of the **show spanning-tree vlan 3 active** command.

Example 3-15. SW1's List of Forwarding Interfaces in VLAN 3

Click here to view code image

```
SW1# show spanning-tree vlan 3 active

VLAN0003
Spanning tree enabled protocol ieee
Root ID Priority 20483
Address f47f.35cb.d780
Cost 1
Port 26 (GigabitEthernet0/2)
Hello Time 2 sec Max Age 20 sec Forward Delay 15 sec

Bridge ID Priority 32771 (priority 32768 sys-id-ext 3)
Address 1833.9d7b.0e80
Hello Time 2 sec Max Age 20 sec Forward Delay 15 sec
Aging Time 300 sec

Interface Role Sts Cost Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------------
Fa0/11 Desg FWD 19 128.11 P2p Edge
Fa0/12 Desg FWD 19 128.12 P2p
Gi0/1 Desg FWD 4 128.25 P2p
Gi0/2 Root FWD 1 128.26 P2p
```

Note that SW1 will not forward the frame back out Fa0/11, as the frame came in on Fa0/11. Also, SW1 will forward the frame out both trunk interfaces (Gi0/1 and Gi0/2), and out Fa0/12. Also, earlier in this chapter, Example 3-14 shows evidence that both SW1's trunks use 802.1Q, with native VLAN 1, so SW1 will add an 802.1Q header, with VLAN ID 3, to each copy of the broadcast frame sent over those two trunks.

SW1's actions mean that both SW2 and SW3 should receive a copy of the broadcast frame sent by PC1. In SW2's case, SW2 happens to discard its copy of PC1's broadcast frame received on SW2's Gi0/2 interface. SW2 discards the frame because of Step 3 of the generic forwarding process from earlier in this chapter, because SW2's incoming interface (Gi0/2) is in a blocking state in VLAN 3, as shown in Example 3-16.

Example 3-16. SW2: Blocking on Gi0/2, Ignoring the Incoming Broadcast Frame

Click here to view code image

```
SW2# show spanning-tree vlan 3

VLAN0003
Spanning tree enabled protocol ieee
Root ID Priority 20483
Address f47f.35cb.d780
Cost 4
Port 25 (GigabitEthernet0/1)
Hello Time 2 sec Max Age 20 sec Forward Delay 15 sec

Bridge ID Priority 32771 (priority 32768 sys-id-ext 3)
Address 1833.9d7b.1380
Hello Time 2 sec Max Age 20 sec Forward Delay 15 sec
Aging Time 300 sec

Interface Role Sts Cost Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------------
Fa0/9 Desg FWD 19 128.9 P2p
Gi0/1 Root FWD 4 128.25 P2p
Gi0/2 Altn BLK 4 128.26 P2p
```

Note that SW2's blocking state did not prevent SW1 from sending the frame to SW2; instead, SW2 silently discards the received frame.

For the copy of PC1's broadcast frame received by SW3 on its Gi0/1 interface, SW3 floods the frame. SW3 determines the frame's VLAN based on the incoming 802.1Q header and finds the incoming interface in an STP forwarding state. Based on these facts, SW3 will forward the frame inside VLAN 3. Example 3-17 shows the information that's needed to know on which interfaces SW3 forwards the VLAN 3 broadcast.

Example 3-17. SW3: Forwarding a Broadcast in VLAN 3

Click here to view code image

```
SW3# show mac address-table dynamic vlan 3
Mac Address Table
-------------------------------------------

Vlan Mac Address Type Ports
---- ----------- -------- -----
3 0200.0101.0101 DYNAMIC Gi0/2
3 0200.1111.1111 DYNAMIC Gi0/1
3 0200.2222.2222 DYNAMIC Gi0/1
3 0200.3333.3333 DYNAMIC Fa0/13
Total Mac Addresses for this criterion: 4

SW3# show spanning-tree vlan 3 active
VLAN0003
Spanning tree enabled protocol ieee
Root ID Priority 20483
Address f47f.35cb.d780
This bridge is the root
Hello Time 2 sec Max Age 20 sec Forward Delay 15 sec

Bridge ID Priority 20483 (priority 20480 sys-id-ext 3)
Address f47f.35cb.d780
```

```
Hello Time 2 sec Max Age 20 sec Forward Delay 15 sec
Aging Time 300 sec

Interface Role Sts Cost Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------------
Fa0/13 Desg FWD 19 128.13 P2p
Gi0/1 Desg FWD 4 128.25 P2p
Gi0/2 Desg FWD 4 128.26 P2p
```

As with SW1, SW3 does not forward the broadcast out the same interface in which the frame arrived (Gi0/1 in this case), but SW3 does flood the frame out all other interfaces in that VLAN and in an STP forwarding state, namely Fa0/13 and Gi0/2. Also, because SW3's Gi0/2 interface currently uses 802.1Q trunking, with native VLAN 1, SW3 adds an 802.1Q header with VLAN ID 3 listed.

Finally, when SW2 receives the copy of the broadcast in SW2's Gi0/1 interface, from SW3, SW2 follows the same generic process as the other switches. SW2 identifies the VLAN based on the incoming 802.1Q header, confirms that the incoming interface is in a forwarding state, and floods the broadcast out all its interfaces that are both in a forwarding state and in VLAN 3. In this case, SW2 forwards the frame only out interface Fa0/9, connected to Router R1. Example 3-18 shows the supporting command output.

Example 3-18. SW2: Forwarding a Broadcast in VLAN 3 Received from SW3

Click here to view code image

```
! First, note that the broadcast address FFFF.FFFF.FFFF is not
! in the VLAN 3 MAC table.
SW2# show mac address-table dynamic vlan 3
Mac Address Table
-------------------------------------------

Vlan Mac Address Type Ports
---- ----------- -------- -----
3 0200.0101.0101 DYNAMIC Fa0/9
3 0200.1111.1111 DYNAMIC Gi0/1
3 0200.2222.2222 DYNAMIC Gi0/1
3 0200.3333.3333 DYNAMIC Gi0/1
3 f47f.35cb.d79a DYNAMIC Gi0/1
Total Mac Addresses for this criterion: 5

! Next, note that on Fa0/9 and Gi0/1 are in an STP forwarding state,
! and the broadcast came in Gi0/1 - so SW2 floods the frame only out Fa0/9.
SW2# show spanning-tree vlan 3 active
!lines omitted for brevity

Interface Role Sts Cost Prio.Nbr Type
---------------- ---- --- --------- -------- --------------------------------
Fa0/9 Desg FWD 19 128.9 P2p
Gi0/1 Root FWD 4 128.25 P2p
Gi0/2 Altn BLK 4 128.26 P2p
```

SW2 does not forward the frame out Gi0/1 because the frame entered SW2's Gi0/1 interface.

R1 ARP Reply (Unicast)

The response from R1, an ARP Reply, flows as a unicast frame. The destination L2 MAC address of R1's ARP reply is PC1's MAC addresses. Figure 3-8 at the end of this topic shows the path, but the figure is shown there, instead of here, to avoid spoiling the answer for anyone using this example as an exercise.

The ARP Reply flows inside an Ethernet frame addressed to PC1's unicast Ethernet address: 0200.1111.1111. When SW2 receives this frame from R1, SW2 notes that the frame entered interface Fa0/9, an access interface in VLAN 3. The end of Example 3-18 previously showed Fa0/9 on SW2 in an STP forwarding state in VLAN 3, so SW2 will attempt to forward the frame in VLAN 3. As seen next in Example 3-19, SW2's MAC address table lists PC1's MAC address—0200.1111.1111—off interface Gi0/1 and in VLAN 3, so SW2 forwards the frame out Gi0/1 to SW3.

Example 3-19. SW2's Logic When Forwarding a Known Unicast to PC1

Click here to view code image

```
SW2# show mac address-table dynamic vlan 3
```

```
Mac Address Table
-------------------------------------------

Vlan Mac Address Type Ports
---- ----------- -------- -----
3 0200.0101.0101 DYNAMIC Fa0/9
3 0200.1111.1111 DYNAMIC Gi0/1
3 0200.2222.2222 DYNAMIC Gi0/1
3 0200.3333.3333 DYNAMIC Gi0/1
3 f47f.35cb.d79a DYNAMIC Gi0/1
Total Mac Addresses for this criterion: 5
```

When SW3 receives the frame destined to PC1's MAC address, from SW2, SW3 first looks at the incoming interface. SW3 notes that the frame entered interface Gi0/2, a trunking interface, and that the trunking header listed VLAN ID 3. The end of Example 3-17 previously showed Gi0/2 in an STP forwarding state in VLAN 3 (forwarding Step 3), so SW3 will not discard the received frame because of STP. As seen next in Example 3-20, SW3's MAC address table lists PC1's MAC address—0200.1111.1111—off interface Gi0/1 and in VLAN 3, so SW3 forwards the frame out Gi0/1 to SW1.

Example 3-20. SW3's Logic When Forwarding a Known Unicast to PC1

Click here to view code image

```
SW3# show mac address-table dynamic vlan 3
Mac Address Table
-------------------------------------------

Vlan Mac Address Type Ports
---- ----------- -------- -----
3 0200.0101.0101 DYNAMIC Gi0/2
3 0200.1111.1111 DYNAMIC Gi0/1
3 0200.2222.2222 DYNAMIC Gi0/1
3 0200.3333.3333 DYNAMIC Fa0/13
Total Mac Addresses for this criterion: 4
```

When SW1 receives the frame from SW3, SW1 notes that the frame entered interface Gi0/2, a trunking interface, and that the trunking header listed VLAN ID 3. The end of Example 3-15 previously showed SW1's Gi0/2 in an STP forwarding state in VLAN 3, so SW1 will process the frame, and not ignore it, because that interface is not in an STP Blocking state in VLAN 3. As shown next in Example 3-21, SW1's MAC address table lists PC1's MAC address—0200.1111.1111—off interface Fa0/11, so SW1 forwards the frame out Fa0/11 to PC1. In this case, SW1 strips off the 802.1Q VLAN header, because interface Fa0/11 is an access interface.

Example 3-21. SW1's Logic When Forwarding a Known Unicast to PC1

Click here to view code image

```
SW1# show mac address-table dynamic vlan 3
Mac Address Table
-------------------------------------------

Vlan Mac Address Type Ports
---- ----------- -------- -----
3 0200.2222.2222 DYNAMIC Fa0/12
3 0200.3333.3333 DYNAMIC Gi0/2
3 f47f.35cb.d799 DYNAMIC Gi0/2
Total Mac Addresses for this criterion: 3

SW1# show mac address-table vlan 3
Mac Address Table
-------------------------------------------

Vlan Mac Address Type Ports
---- ----------- -------- -----
All 0100.0ccc.cccc STATIC CPU
All 0100.0ccc.cccd STATIC CPU
All 0180.c200.0000 STATIC CPU
All 0180.c200.0001 STATIC CPU
All 0180.c200.0002 STATIC CPU
All 0180.c200.0003 STATIC CPU
All 0180.c200.0004 STATIC CPU
All 0180.c200.0005 STATIC CPU
All 0180.c200.0006 STATIC CPU
All 0180.c200.0007 STATIC CPU
All 0180.c200.0008 STATIC CPU
All 0180.c200.0009 STATIC CPU
All 0180.c200.000a STATIC CPU
All 0180.c200.000b STATIC CPU
All 0180.c200.000c STATIC CPU
All 0180.c200.000d STATIC CPU
All 0180.c200.000e STATIC CPU
All 0180.c200.000f STATIC CPU
All 0180.c200.0010 STATIC CPU
All ffff.ffff.ffff STATIC CPU
3 0200.1111.1111 STATIC Fa0/11
3 0200.2222.2222 DYNAMIC Fa0/12
3 0200.3333.3333 DYNAMIC Gi0/2
3 f47f.35cb.d799 DYNAMIC Gi0/2
Total Mac Addresses for this criterion: 24
```

This last step points out an important fact about the MAC address table and port security. Note that the **show mac address-table dynamic** command on SW1 does not list PC1's MAC address of 0200.1111.1111, so you might have been tempted to think that SW1 will flood the frame because it is an unknown unicast frame. However, because SW1 has configured port security on Fa0/11, including the **switchport port-security mac-address 0200.1111.1111** interface subcommand, IOS considers this MAC address a static MAC address. So, by leaving off the **dynamic** keyword, the **show mac address-table vlan 3** command lists all MAC addresses known in the VLAN, including 0200.1111.1111. This command output confirms that SW1 will forward the unicast to 0200.1111.1111 only out interface Fa0/11.

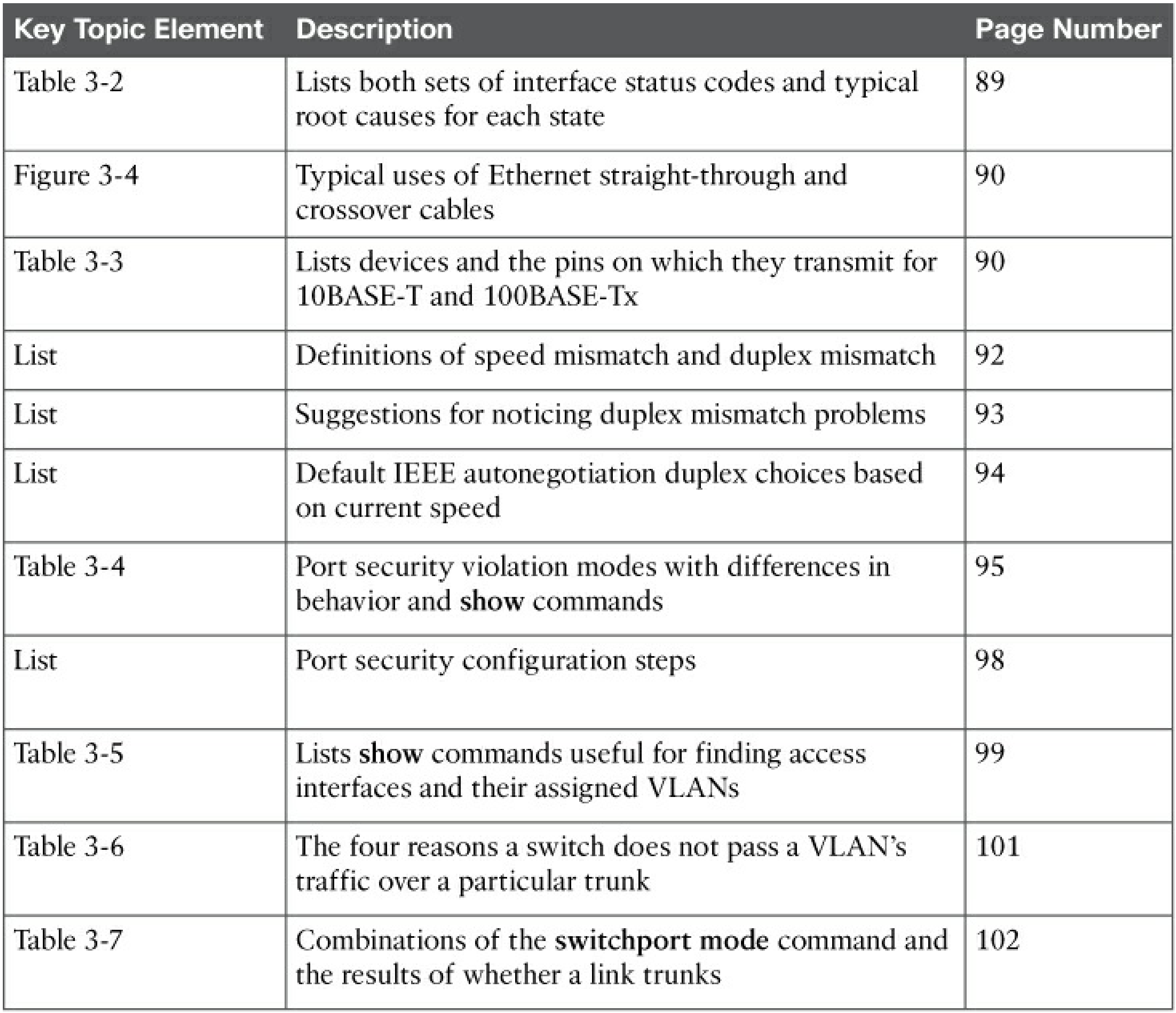
Figure 3-7 shows the flow of the ARP Request (broadcast) through this LAN, and Figure 3-8 shows the flow of the unicast ARP Reply.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 3-8 lists these key topics and where each is discussed.

Table 3-8. Key Topics for Chapter 3



Key Topic Element	Description	Page Number
Table 3-2	Lists both sets of interface status codes and typical root causes for each state	89
Figure 3-4	Typical uses of Ethernet straight-through and crossover cables	90
Table 3-3	Lists devices and the pins on which they transmit for 10BASE-T and 100BASE-Tx	90
List	Definitions of speed mismatch and duplex mismatch	92
List	Suggestions for noticing duplex mismatch problems	93
List	Default IEEE autonegotiation duplex choices based on current speed	94
Table 3-4	Port security violation modes with differences in behavior and **show** commands	95
List	Port security configuration steps	98
Table 3-5	Lists **show** commands useful for finding access interfaces and their assigned VLANs	99
Table 3-6	The four reasons a switch does not pass a VLAN's traffic over a particular trunk	101
Table 3-7	Combinations of the **switchport mode** command and the results of whether a link trunks	102

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix D, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix E, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Answers to Troubleshooting Example 1

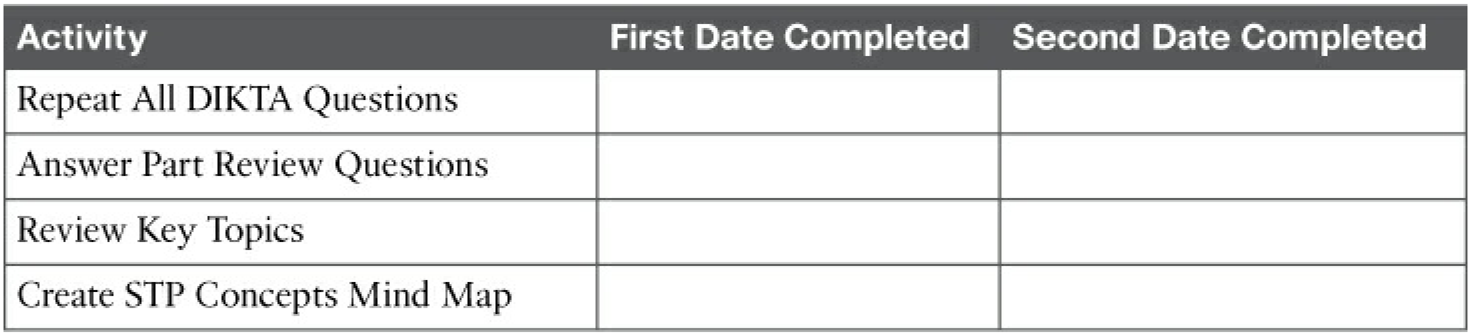
For those of you who used Troubleshooting Example 1 as an exercise, the following list summarizes the problems that could have been uncovered in that exercise:

- Figure 3-5 shows SW2 port Fa0/10 connected to Router R1, while CDP showed that, in reality, SW2's F0/9 port is used. The example fixed the problem by updating the network diagram to list Fa0/9.
- SW1's F0/12 port, presumably connected to PC2 per Figure 3-5, is in a notconnect state. The examples could not identify the specific reason for the notconnect state. (In reality, the cable was unplugged; the cable was plugged in, in preparation for the second example.)
- SW3's Fa0/13 port is possibly in a duplex mismatch state. It lists a speed/duplex setting of a-100/a-half, which can happen if the other device (PC13) disables autonegotiation and sets itself for 100/full and disables autonegotiation. The problem was fixed by manually configuring the switch to also use full duplex.
- Port security on SW1's F0/11 port is filtering traffic from the only device connected to that port (PC1, 0200.1111.1111), because of its incorrect configuration of MAC address 0200.3333.3333. The port security configuration was updated to list the correct 0200.1111.1111 MAC address.
- SW2, port F0/9, which is the port actually connected to R1, is assigned to VLAN 1, while port F0/10, the port that Figure 3-5 shows as connected to R1, is assigned to (correct) VLAN 3. Either the cable should be moved or F0/9 needs to be placed into VLAN 3. The book shows the reconfiguration of SW2's F0/9 port with the **switchport access vlan 3** command.

Part I Review

Keep track of your part review progress with the checklist in Table P1-1. Details about each task follow the table.

Table P1-1. Part I Part Review Checklist



Activity	First Date Completed	Second Date Completed
Repeat All DIKTA Questions		
Answer Part Review Questions		
Review Key Topics		
Create STP Concepts Mind Map		

Repeat All DIKTA Questions

For this task, answer the "Do I Know This Already?" questions again for the chapters in Part I of this book using the PCPT software. See the section "How to View Only DIKTA Questions by Part" in the Introduction to this book to learn how to make the PCPT software show you DIKTA questions for this part only.

Answer Part Review Questions

For this task, answer the Part Review questions for this part of the book using the PCPT software. See the section "How to View Only DIKTA Questions by Part" in the Introduction to this book to learn how to make the PCPT software show you DIKTA questions for this part only.

Review Key Topics

Key Topic

Browse back through the chapters and look for the Key Topic icons. If you do not remember some details, take the time to reread those topics.

Create STP Concepts Mind Map

Spanning Tree Protocol (STP) defines a lot of ideas that you might find hard to mentally organize. Create a mind map to help organize STP concepts into three areas, as follows:

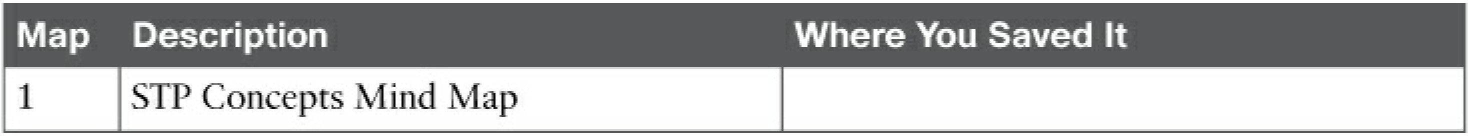
- **Rules:** Rules include any of the rules a switch uses when making choices (for instance, the rules about how switches choose the root switch).
- **Roles:** STP defines both roles and states; an example of a role is the root port role.
- **States:** For example, forwarding.

Create a mind map with three branches (rules, roles, and states) and fill in as many ideas about each that you can recall.

> **Note**
>
> For more information about mind mapping, see the section "About Mind Maps" in the Introduction to this book.

Create the mind maps in Table P1-2 on paper using any mind mapping software (or even any drawing application). If you use an application, note for later reference the filename and location where you saved the file. Appendix F, "Mind Map Solutions," provides sample mind map answers.

Table P1-2. Configuration Mind Maps for Part I Review



Map	Description	Where You Saved It
1	STP Concepts Mind Map	

Finally, keep the following important points in mind when working on this project:

- Most of the learning with this exercise happens when you do it; jumping straight to the sample in Appendix F may be tempting but does not help you learn as much.
- Use as few words as possible for you to remember the thought. Do not attempt to write complete phrases or sentences.

- Do not look at the book or your notes at first. After you have completed the mind map as much as you can from memory, only then look back at your notes.
- Repeat this exercise from scratch, without notes, later in your study, as a way to strengthen your mental connectors and memory.

Part II: IP Version 4 Routing

Chapter 4: Troubleshooting IPv4 Routing Part I

Chapter 5: Troubleshooting IPv4 Routing Part II

Chapter 6: Creating Redundant First-Hop Routers

Chapter 7: Virtual Private Networks

Part II Review

Part II of this book turns this book's attention away from the LAN topics in Part I, moving on to IPv4 routing. The ICND1 book (and exam) introduced many details of IPv4 routing—the concepts, all the subnetting math, and the implementation details on routers—and now Part II of this book goes further. This part reviews the IPv4 routing topics from ICND1, but now with an eye toward troubleshooting problems with IPv4 internetworks, with the entirety of Chapters 4 and 5 devoted to troubleshooting IPv4 routing.

The last two chapters in this part add new topics as compared with ICND1's coverage of IPv4, with two unrelated topics. Chapter 6 introduces the idea of having redundant default routers, and Chapter 7 discusses how to create a private network connection using IPv4 over the Internet.

Chapter 4. Troubleshooting IPv4 Routing Part I

This chapter covers the following exam topics:

Troubleshooting

- Identify and correct common network problems
- Troubleshoot and resolve routing issues
  - routing is enabled
  - routing table is correct
  - correct path selection

IPv4 routing requires the cooperation of hosts and routers. Hosts first create IPv4 packets and send those packets to some nearby router (the host's default router, or default gateway). The router then makes a routing decision of where to forward the IPv4 packet next and sends the packet over the next physical link. Each router that receives the IPv4 packet repeats the process, until the packet finally arrives at the destination host.

This chapter focuses on how to troubleshoot problems with IPv4 routing. Specifically, this chapter focuses on packet forwarding (that is, the data plane of IPv4). For the most part, this chapter leaves most of the discussion of data link and physical layer problems to Part I (LANs) and Part IV (WANs), instead focusing on the network layer functions for IP routing. This chapter also leaves the discussion of IPv4 control plane issues, specifically IP routing protocols, to Part III (IP Version 4 Routing Protocols) of this book.

This chapter reviews IPv4 routing as a means to an end: to help you learn how to troubleshoot IPv4 routing issues. Cisco put most IPv4 routing concepts, configuration, and verification topics into the ICND1 exam's side of the scope of CCNA, but the troubleshooting of those same topics into the ICND2 side of CCNA. As a result, this book holds the IPv4 troubleshooting chapters; so to help make sense of the details, this book weaves IPv4 review topics throughout the chapter.

This chapter breaks the materials into three major sections, with all three presenting the information from the perspective of troubleshooting a network. The first section reviews IPv4 routing on hosts and routers; that knowledge can be used to predict normal operation when troubleshooting a network problem. The second section discusses the **ping** command, specifically how this command can isolate a problem to smaller and smaller parts of the network and fewer and fewer reasons—always driving toward finding the root cause. The final section focuses on traceroute, with the same goal as the ping section: looking for ways to isolate the problem.

"Do I Know This Already?" Quiz

The troubleshooting chapters of this book pull in concepts from many other chapters, including some chapters in *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*. They also show you how to approach some of the more challenging questions on the CCNA exams. Therefore, it is useful to read these chapters regardless of your current knowledge level. For these reasons, the troubleshooting chapters do not include a "Do I Know This Already?" quiz. However, if you feel particularly confident about troubleshooting IP routing features covered in this book and *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*, feel free to move to the "Exam Preparation Tasks" section near the end of this chapter to bypass the majority of the chapter.

Foundation Topics

Predicting Normal IPv4 Routing Behavior

Different people solve networking problems with different methods. No one method can lay claim as the best method in all conditions. However, as mentioned in Chapter 3, "Troubleshooting LAN Switching," when learning how to troubleshoot, it helps to take some systematic approach to troubleshooting. So, this chapter (as do the other troubleshooting topics in this book) approaches problems with the same general strategy, as follows:

1. Predict how things should work normally.
2. When a problem occurs, isolate the problem to as specific a reason as possible on as few devices as possible.
3. Discover and fix the root cause of the problem.

This first major section of the chapter reviews IPv4 routing, for the purpose of the first step in this troubleshooting process:

predicting what happens normally when an IPv4 packet flows from one host to another.

So, how does IPv4 routing work? When focusing on the network layer logic, any internetwork can be viewed as a series of routing steps. The first step begins with a host creating and sending the packet to its default router. After the packet arrives at a router, one or more routers forward (route) the packet until it arrives at the destination, as shown in the first three steps of the example in Figure 4-1.

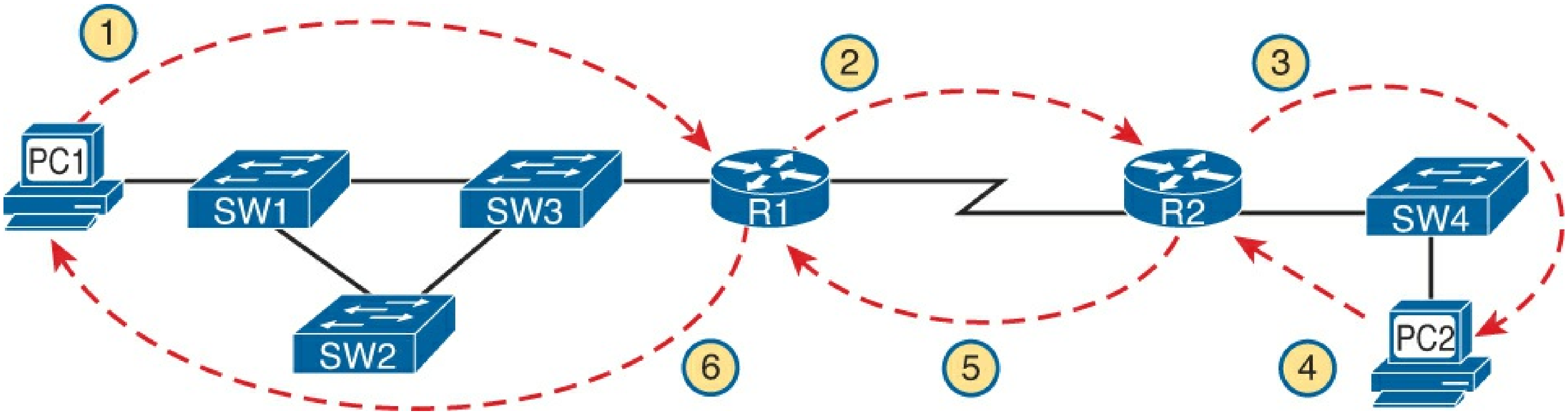


Figure 4-1. Major Steps in an IP Forwarding Example

The first three steps in the example of Figure 4-1 show how to route a packet over an internetwork. However, most applications require packet flow in both directions. So, when troubleshooting, any analysis of normal operations should also consider the packet that will be sent back to the first host (PC1 in this case), as shown in Steps 4, 5, and 6 in the figure.

To deliver an IPv4 packet end to end from one host to another and back, hosts and routers must cooperate. This section breaks down the logic based on the host logic first and then the router logic.

Host IPv4 Routing Logic

The IPv4 routing process starts with the host that creates the IP packet. After the host has created the IP packet, the host asks this question: Is the destination IP address of this new packet in my local subnet? The host uses its own IP address/mask to determine the range of addresses in the local subnet, compares that range to the destination IP address, and then chooses as follows:

Key Topic

1. If the destination is local, send directly:
    - **A.** Find the destination host's MAC address. Use the already-known Address Resolution Protocol (ARP) table entry, or use ARP messages to learn the information.
    - **B.** Encapsulate the IP packet in a data link frame with the destination data link address of the *destination host*.
2. If the destination is not local, send to the default router (default gateway):
    - **A.** Find the default router's MAC address. Use the already known ARP table entry, or use ARP messages to learn the information.
    - **B.** Encapsulate the IP packet in a data link frame with the destination data link address of the *default router*.

These detailed steps in the list do summarize host IPv4 routing logic, but Figure 4-2 summarizes the big decision on the left side of the figure. The figure shows host A sending a local packet directly to host D. However, for packets to host B—on the other side of a router and therefore in a different subnet—host A sends the packet to its default router (R1).

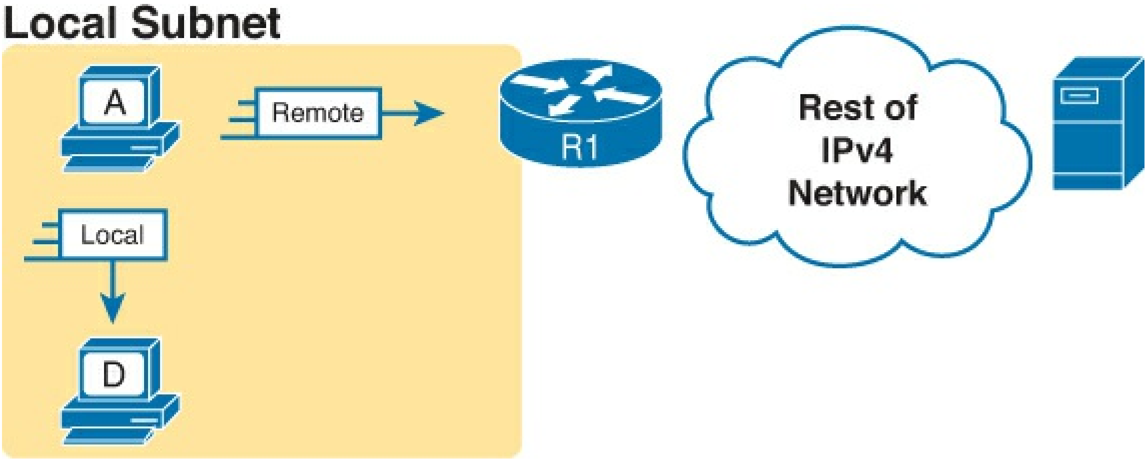


Figure 4-2. Host Routing Logic Summary

Routing Logic Used by IPv4 Routers

Routers act independently. That is, the process of routing a single packet requires a router to go through its own logic without help from any other router.

At the same time, routers act in concert with each other. One router after another forwards a packet so that, eventually, the packet reaches the correct destination host. Each router's independent action forwards the packet over one hop of an end-to-end route to the destination host.

This next topic discusses what routers do to route packets—first as an independent process on one router, and then as an overall effect.

IP Routing Logic on a Single Router

Compared to hosts, routers have a little more work to do to route IPv4 packets. While the host logic begins with an IP packet sitting in memory, a router has some work to do before getting to that point, at which point the router does the most important part: matching the IP routing table. The specific steps are as follows:

Key Topic

Step 1. For each received data link frame, choose whether to process the frame. Process it if:

- **A.** The frame has no errors (per the data link trailer frame check sequence or FCS field).
- **B.** The frame's destination data link address is the router's address (or an appropriate multicast or broadcast).

Step 2. If choosing to process the frame at Step 1, deencapsulate the packet from inside the data link frame.

Step 3. Make a routing decision. To do so, compare the packet's destination IP address to the routing table and find the route that matches the destination address. This route identifies the outgoing interface of the router and possibly the next-hop router.

Step 4. Encapsulate the packet into a data link frame appropriate for the outgoing interface. When forwarding out Ethernet LAN interfaces, this may require the use of ARP if the next device's MAC address is not in the ARP cache of the router.

Step 5. Transmit the frame out the outgoing interface, as listed in the matched IP route.

> **Note**
>
> The step numbers in this list do not matter. The concepts inside each step matter a lot. So, know them! For the exams, though, you do not need to memorize which idea goes with a particular step number.

This detailed list is accurate, but sometimes it helps to think about routing in simpler terms, like in this one-sentence summary:

> The router receives a frame, removes the packet from inside the frame, decides which interface to forward the packet out of, puts the packet into another frame, and sends the frame (with packet inside it) out the correct router interface.

Although reading text about how routing works might be useful, sometimes it helps to see the process as a drawing. Figure 4-3 breaks down the same five-step routing process with a packet that enters a router from the left and exits on the right. A packet arrives from the left, entering a router Ethernet interface, with a destination IP address that is host B's address. Router R1 processes the frame and packet as shown with the numbers in the figure matching the five-step routing process described earlier. Eventually, the router forwards the packet, inside a new High-Level Data Link Control (HDLC) frame, out the serial link on the right.

Key Topic

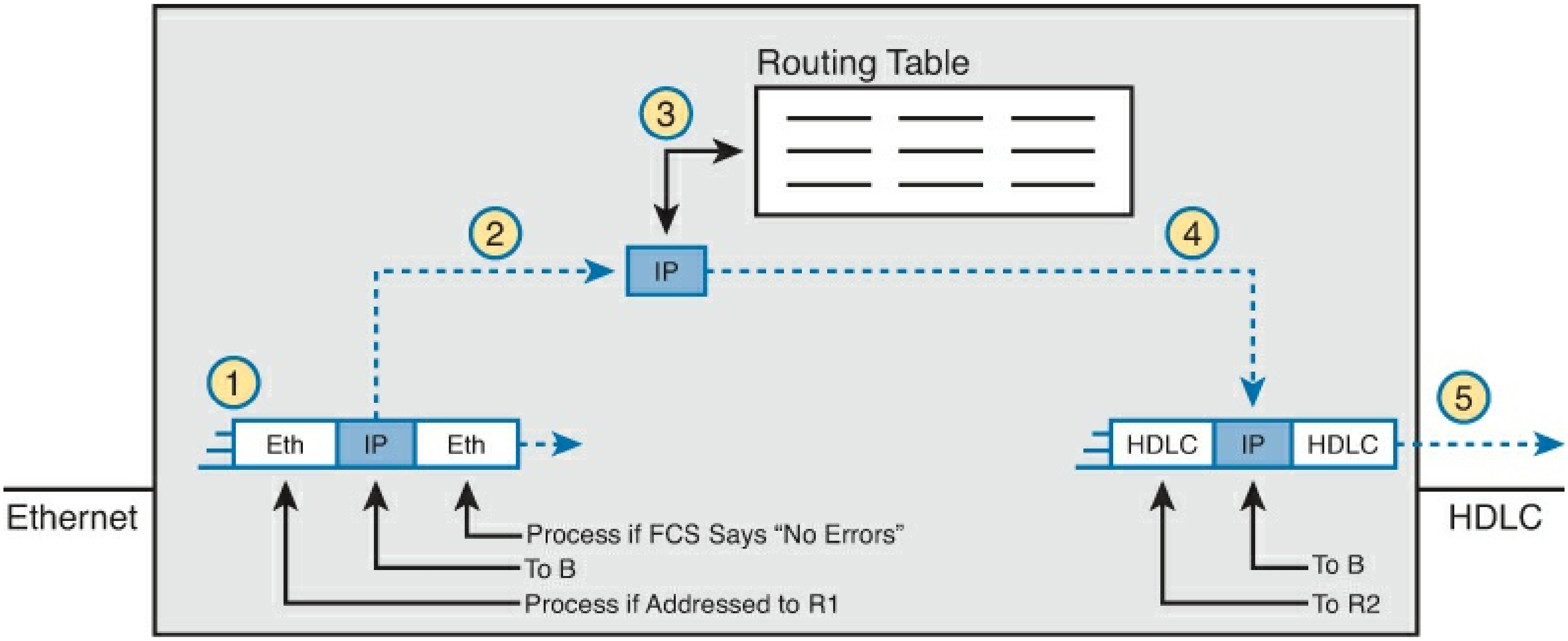

Routing Table
3
2
IP
4
1
Eth
IP
Eth
5
HDLC
IP
HDLC
Ethernet
HDLC
Process if FCS Says "No Errors"
To B
Process if Addressed to R1
To B
To R2

Figure 4-3. Router Routing Logic Summary

IP Routing from Host to Host

So far, this review of routing logic has focused on a single router, with three different views of the process: a long written process, a short written process, and a diagram of the same. But the logic on one router does not deliver the packet from end to end through the IP internetwork. End-to-end delivery requires every router to use the same logic, with IP routes that tell each router to forward the packet to the next router, and the next, and the next, to deliver the packet to the destination.

Figure 4-4 shows the end-to-end effects of routing a packet, focusing on the deencapsulation (Step 2) and encapsulation (Step 4) on each router. Each router discards the incoming frame's data link header and trailer, so each frame moves only from a host to a router or between routers. Each router adds a new data link header and trailer, creating a new frame, each time the router forwards a packet. And the data link header's address fields matter only on that local data link.

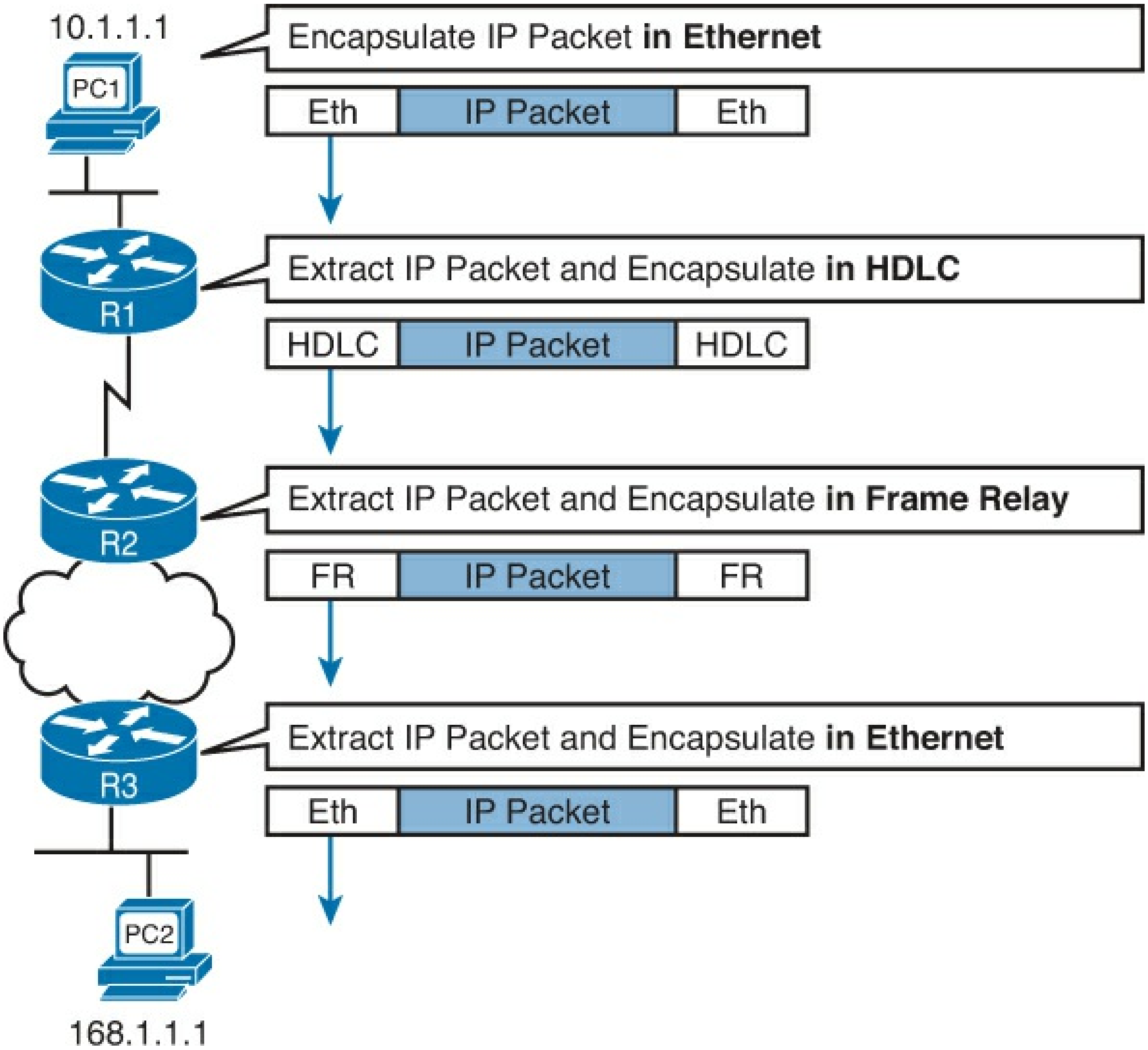

10.1.1.1
PC1
Encapsulate IP Packet in Ethernet
Eth
IP Packet
Eth
R1
Extract IP Packet and Encapsulate in HDLC
HDLC
IP Packet
HDLC
R2
Extract IP Packet and Encapsulate in Frame Relay
FR
IP Packet
FR
R3
Extract IP Packet and Encapsulate in Ethernet
Eth
IP Packet
Eth
PC2
168.1.1.1

Figure 4-4. Encapsulation and Deencapsulation of a Packet When Routed

The figure shows PC1 sending a packet to PC2, with the various frames shown. At the top, PC1 sends an Ethernet frame to R1. R1 then deencapsulates the packet and reencapsulates it in an HDLC frame. R2 repeats the same process, this time encapsulating the packet inside a Frame Relay frame. R3 repeats the process, encapsulating the packet inside an Ethernet frame and sending the frame to PC2.

Building New Data Link Headers Using ARP Information

Another important part of the routing process relates to how a router chooses the data link addresses to use in a new data link header. Data link headers typically list an address, like the MAC addresses used in Ethernet data link headers. To encapsulate an IP packet and send it onto some types of data links, the router has to first know the data link address of the other device on the outgoing link. For instance, in Figure 4-4, router R3 has to know PC2's MAC address before it can build and send a unicast Ethernet frame to PC2 at the bottom of the figure.

To support the process of learning MAC addresses of other devices on LANs, IPv4 uses the Address Resolution Protocol (ARP). ARP defines two messages (ARP Request and ARP Reply). The sending host or router uses an ARP Request to make this request: If this is your IP address, tell me your MAC address. The second host sends back an ARP Reply, listing their IPv4 address and Ethernet MAC address. For instance, Figure 4-5 shows the ARP process that would have occurred in the same network as Figure 4-4, before R3 could have forwarded a packet (encapsulated within a frame) to PC2's MAC address.

Key Topic

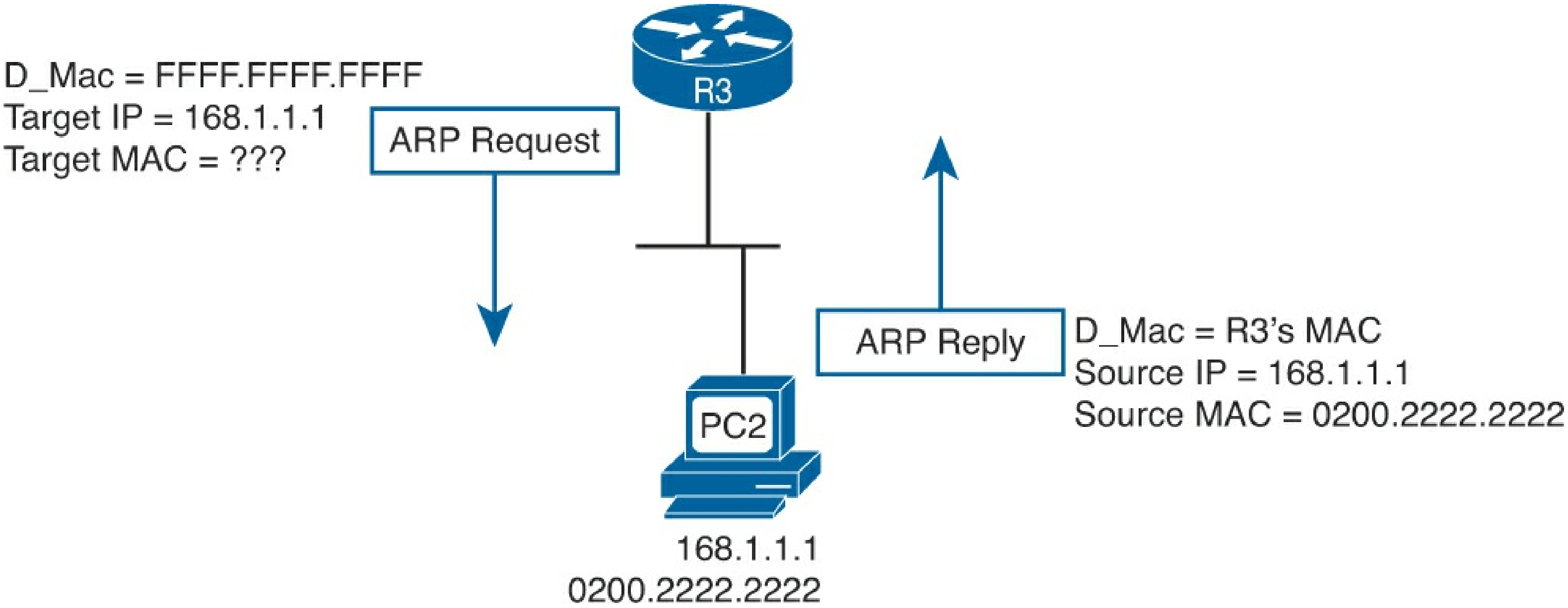


Figure 4-5. Sample ARP Process

The CCENT and CCNA topics include only one LAN data link protocol (Ethernet) and three WAN data link protocols (HDLC, PPP, and Frame Relay), at least to any depth. Ethernet uses ARP, as shown in Figure 4-5. HDLC and PPP, used on serial links in a point-to-point topology, do not need a function like ARP. Frame Relay uses a similar function called Inverse ARP, as discussed later in Chapter 13, "Understanding Frame Relay Concepts."

In summary, hosts forward packets to their default routers when the packet's destination address is in another subnet. Each router deencapsulates the packet, chooses where to forward it, and encapsulates the packet in a new data link frame. Only the IP packet flows from source to destination host, while each data link header/trailer serves as a means to move the packet from host to router, router to router, or router to host.

Now that you understand how hosts and routers forward IPv4 packets, the next two topics look at how to isolate the root cause of a problem using the **ping** and **traceroute** commands. These commands let you rule out parts of the IPv4 routing process, because these commands confirm that parts of the process work.

Problem Isolation Using the ping Command

Someone sends you an email or text, or a phone message, asking you to look into a user's network problem. You Secure Shell (SSH) to a router and issue a **ping** command that works. What does that result rule out as a possible reason for the problem? What does it rule in as still being a possible root cause?

Then you issue another **ping** to another address, and this time the ping fails. Again, what does the failure of that **ping** command tell you? What parts of IPv4 routing may still be a problem, and what parts do you now know are not a problem?

The **ping** command gives us one of the most common network troubleshooting tools. When the **ping** command succeeds, it confirms many individual parts of how IP routing works, ruling out some possible causes of the current problem. When a **ping** command fails, it often helps narrow down where in the internetwork the root cause of the problem may be happening, further isolating the problem.

This section begins with a brief review of how ping works. It then moves on to some suggestions and analysis of how to use the **ping** command to isolate problems by removing some items from consideration.

Ping Command Basics

The **ping** command tests connectivity by sending packets to an IP address, expecting the device at that address to send packets back. The command sends packets that mean "if you receive this packet, and it is addressed to you, send a reply back." Each time the **ping** command sends one of these packets and receives back the message sent back by the other host, the **ping** command knows a packet made it from the source host to the destination and back.

More formally, the **ping** command uses the Internet Control Message Protocol (ICMP), specifically the ICMP Echo Request and ICMP Echo Reply messages. ICMP defines many other messages as well, but these two messages were made specifically for connectivity testing by commands like ping. As a protocol, ICMP does not rely on TCP or UDP, and it does not use any application layer protocol. It exists as a protocol used to assist IP by helping manage the IP network functions.

Figure 4-6 shows the ICMP messages, with IP headers, in an example. In this case, the user at host A opens a command prompt and issues the **ping 172.16.2.101** command, testing connectivity to host B. The command sends one Echo Request, and waits (Step 1); host B receives the messages, and sends back an Echo Reply (Step 2).

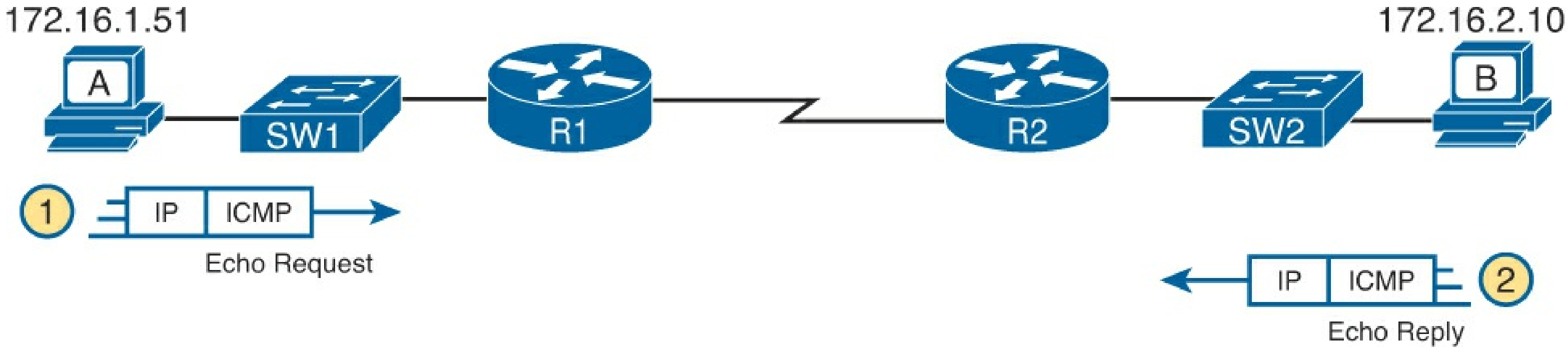


Figure 4-6. Concept Behind ping 172.16.2.101 **on Host A**

The **ping** command is supported on many different devices and many common operating systems. The command has many options: the name or IP address of the destination, how many times the command should send an Echo Request, how long the command should wait (timeout) for an Echo Reply, how big to make the packets, and many other options. Example 4-1 shows a sample from host A, with the same command that matches the concept in Figure 4-6: a **ping 172.16.2.101** command on host A.

Example 4-1. Sample Output from Host A's ping 172.16.2.101 **Command**

Click here to view code image

```
WendellOdoms-iMac:~ wendellodom$ ping 172.16.2.101
PING 172.16.2.101 (172.16.2.101): 56 data bytes
64 bytes from 172.16.2.101: icmp_seq=0 ttl=64 time=1.112 ms
64 bytes from 172.16.2.101: icmp_seq=1 ttl=64 time=0.673 ms
64 bytes from 172.16.2.101: icmp_seq=2 ttl=64 time=0.631 ms
64 bytes from 172.16.2.101: icmp_seq=3 ttl=64 time=0.674 ms
64 bytes from 172.16.2.101: icmp_seq=4 ttl=64 time=0.642 ms
64 bytes from 172.16.2.101: icmp_seq=5 ttl=64 time=0.656 ms
^C
--- 172.16.2.101 ping statistics ---
6 packets transmitted, 6 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 0.631/0.731/1.112/0.171 ms
```

Strategies and Results When Testing with the ping Command

Often, the person handling initial calls from users about problems (often called a customer support rep, or CSR) cannot issue **ping** commands from the user's device. In some cases, talking users through typing the right commands and making the right clicks on their machines can be a problem. Or, the user just might not be available. As an alternative, using different **ping** commands from different routers can help isolate the problem.

Note

For the exam, it helps to practice pinging from the routers, as discussed in the next several pages.

The problem with using **ping** commands from routers, instead of from the host that has the problem, is that no single router **ping** command can exactly replicate a **ping** command done from the user's device. However, each different **ping** command can help isolate a problem further. The rest of this section of **ping** commands discusses troubleshooting IPv4 routing by using various **ping** commands from the command-line interface (CLI) of a router.

Testing Longer Routes from Near the Source of the Problem

Most problems begin with some idea like "host X cannot communicate with host Y." A great first troubleshooting step is to issue a **ping** command from X for host Y's IP address. However, assuming the engineer does not have access to host X, the next best test is to ping host X's IP address from the router nearest the host that has the problem.

For instance, in Figure 4-6, imagine that the user of host A had called IT support with a problem related to sending packets to host B. A **ping 172.16.2.101** command on host A would be a great first troubleshooting step, but the CSR cannot access host A or get in touch with the user of host A. So, the CSR telnets to router R1, and pings host B from there, as shown in Example 4-2.

Example 4-2. Router R2 Pings Host B (Two Commands)

Click here to view code image

```
R1# ping 172.16.2.101
```

```
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.101, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 1/2/4 ms
R1# ping 172.16.2.101
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.101, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/2/4 ms
```

First, take a moment to review the output of the first IOS **ping** command. By default, the Cisco IOS **ping** command sends five Echo messages, with a timeout of 2 seconds. If the command does not receive an Echo Reply within 2 seconds, the command considers that message to be a failure, and the command lists a period. If a successful reply is received within 2 seconds, the command displays an exclamation point. So, in this first command, the first Echo Reply timed out, whereas the other four received a matching Echo Reply within 2 seconds.

As a quick aside, the example shows a common and normal behavior with **ping** commands: the first **ping** command shows one failure to start, but then the rest of the messages work. This usually happens because some device in the end-to-end route is missing an ARP table entry.

Now think about troubleshooting and what a working **ping** command tells us about the current behavior of this internetwork. First, focus on the big picture for a moment:

- R1 can send ICMP Echo Request messages to host B (172.16.2.101).
- R1 sends these messages from its outgoing interface's IP address (by default), 172.16.4.1 in this case.
- Host B can send ICMP Echo Reply messages to R1's 172.16.4.1 IP address (hosts send Echo Reply messages to the IP address from which the Echo Request was received).

Figure 4-7 shows the packet flow.

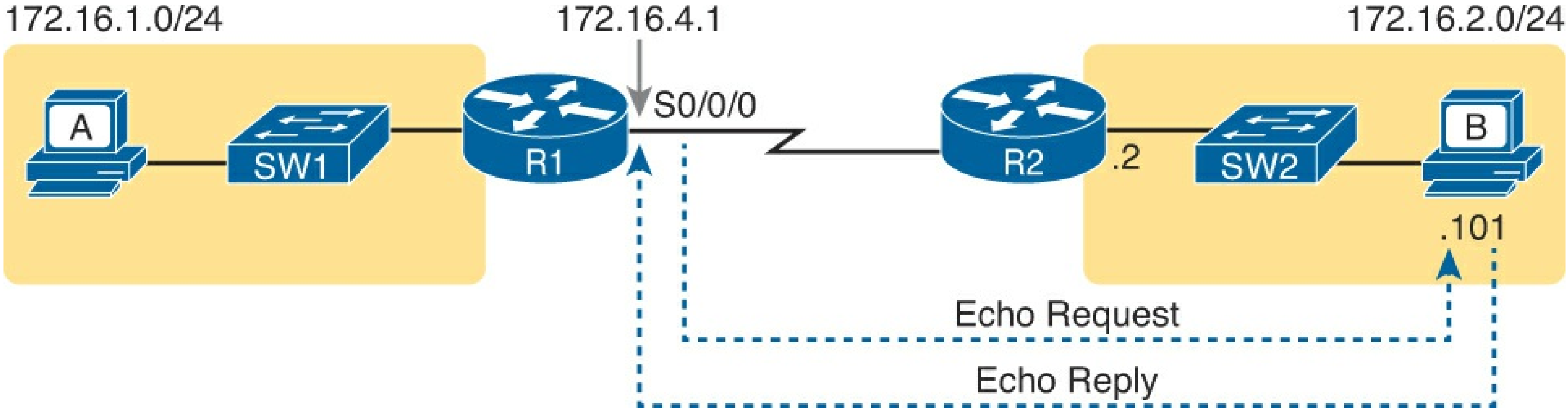


Figure 4-7. Standard ping 172.6.2.101 **Command Using the Source Interface IP Address**

Next, think about IPv4 routing. In the forward direction, R1 must have a route that matches host B's address (172.16.2.101); this route will be either a static route or one learned with a routing protocol. R2 also needs a route for host B's address, in this case a connected route to B's subnet (172.16.2.0/24), as shown in the top arrow lines in Figure 4-8.

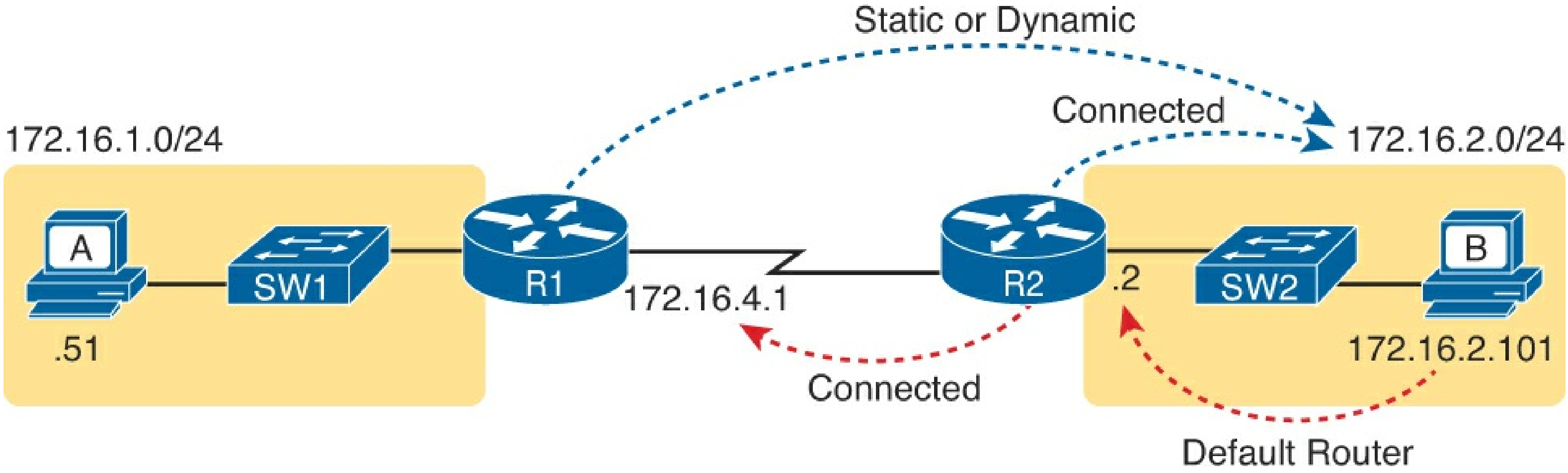


Figure 4-8. Layer 3 Routes Needed for R1's Ping 172.16.2.101 to Work

The arrow lines on the bottom of Figure 4-8 shows the routes needed to forward the ICMP Echo Reply message back to router R1's 172.16.4.1 address. First, host B must have a valid default router setting because 172.16.4.1 sits in a different subnet than host B. R2 must also have a route that matches destination 172.16.4.1 (in this case, likely to be a connected route).

The working **ping** commands in Example 4-2 also require the data link and physical layer details to be working. The serial link must be working: The router interfaces must be up/up, which typically indicates that the link can pass data. On the LAN, R2's LAN interface must be in an up/up state. In addition, everything discussed about Ethernet LANs must be working because the **ping** confirmed that the packets went all the way from R1 to host B and back. In particular

- The switch interfaces in use are in a connected (up/up) state.
- Port security does not filter frames sent by R2 or host B.
- STP has placed the right ports into a forwarding state.

Note

While this figure shows a small LAN with one switch, if a larger LAN existed, with many switches, a working ping confirms that STP has indeed converged to a working topology.

The **ping 172.16.2.101** in Example 4-2 also confirms that IP access control lists (ACL) did not filter the ICMP messages. As a reminder, an ACL on a router does not filter packets created on that same router, so R1 would not have filtered its own ICMP Echo Request message. The rest of the ICMP messages could have been filtered entering or exiting the router interfaces. Figure 4-9 shows the locations where an IP ACL could have filtered the messages generated as a result of R1's **ping 172.16.2.101** command.

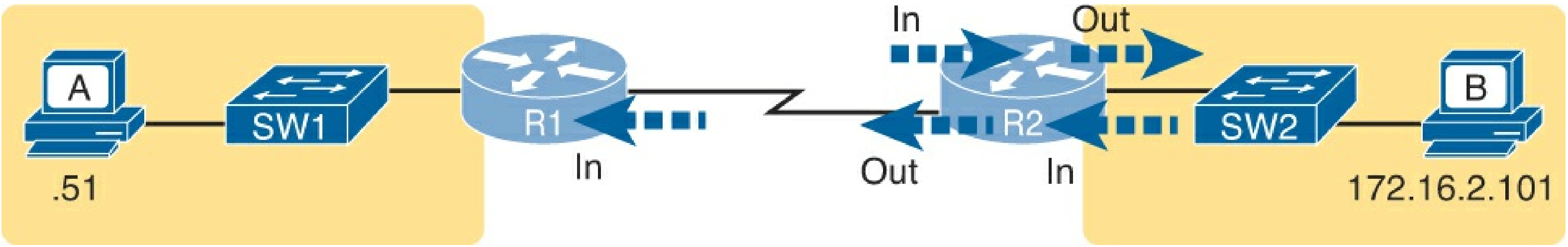


Figure 4-9. Locations Where IP ACLs Could Have Filtered the Ping Messages

Finally, the working **ping 172.16.2.101** command on R1 can also be used to reasonably predict that ARP worked on R2 and host B and that switch SW2 learned MAC addresses for its MAC address table. R2 and host B need to know each other's MAC addresses so that they can encapsulate the IP packet inside an Ethernet frame, which means both must have a matching ARP table entry. The switch learns the MAC address used by R2 and by host B when it sends the ARP messages or when it sends the frames that hold the IP packets. Figure 4-10 shows the type of information expected in those tables.

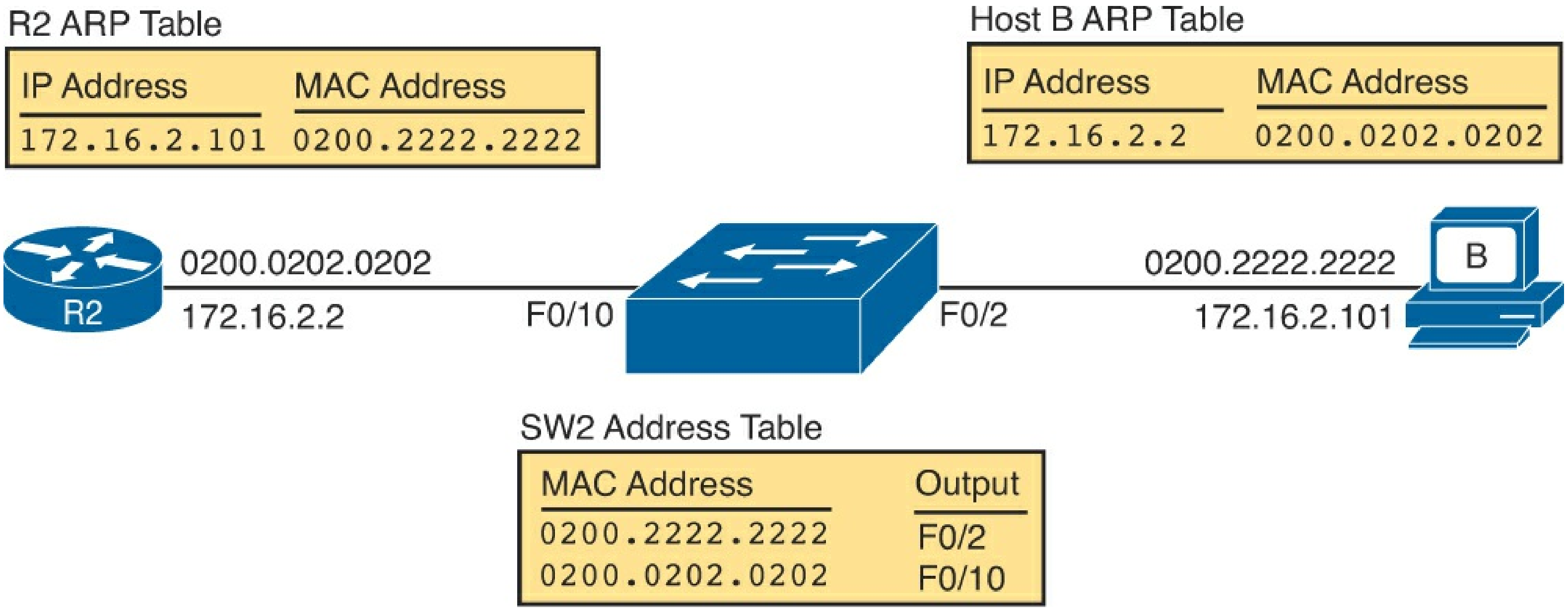

R2 ARP Table
IP Address
MAC Address
172.16.2.101
0200.2222.2222
Host B ARP Table
IP Address
MAC Address
172.16.2.2
0200.0202.0202
R2
0200.0202.0202
172.16.2.2
F0/10
F0/2
0200.2222.2222
172.16.2.101
B
SW2 Address Table
MAC Address
Output
0200.2222.2222
F0/2
0200.0202.0202
F0/10

Figure 4-10. ARP and MAC Address Tables

As you can see from the last few pages, a strategy of using a **ping** command from near the source of the problem can rule out a lot of possible root causes of any problems between two hosts—assuming the **ping** command succeeds. However, this **ping** command does not act exactly like the same **ping** command on the actual host. To overcome some of what is missing in the **ping** command from a nearby router, the next several examples show some strategies for testing other parts of the path between the two hosts that may have a current problem.

Using Extended Ping to Test the Reverse Route

Pinging from the default router, as discussed in the past few pages, misses an opportunity to test IP routes more fully. In particular, it does not test the reverse route back toward the original host.

For instance, referring back to the internetwork in Figure 4-7 again, note that the reverse routes do not point to an address in host A's subnet. When R1 processes the **ping 172.16.2.101** command, R1 has to pick a source IP address to use for the Echo Request, and routers choose the *IP address of the outgoing interface*. The Echo Request from R1 to host B flows with source IP address 172.16.4.1 (R1's S0/0/0 IP address). The Echo Reply flows back to that same address (172.16.4.1).

The standard **ping 172.16.2.101** command on R1 does not test whether the routers can route back to subnet 172.16.1.0/24. A better ping test would test the route back to host A's subnet; an extended ping from R1 can cause that test to happen. Extended ping allows R1's **ping** command to use R1's LAN IP address from within subnet 172.16.1.0/24. Then, the Echo Reply messages would flow to host A's subnet, as shown in Figure 4-11.

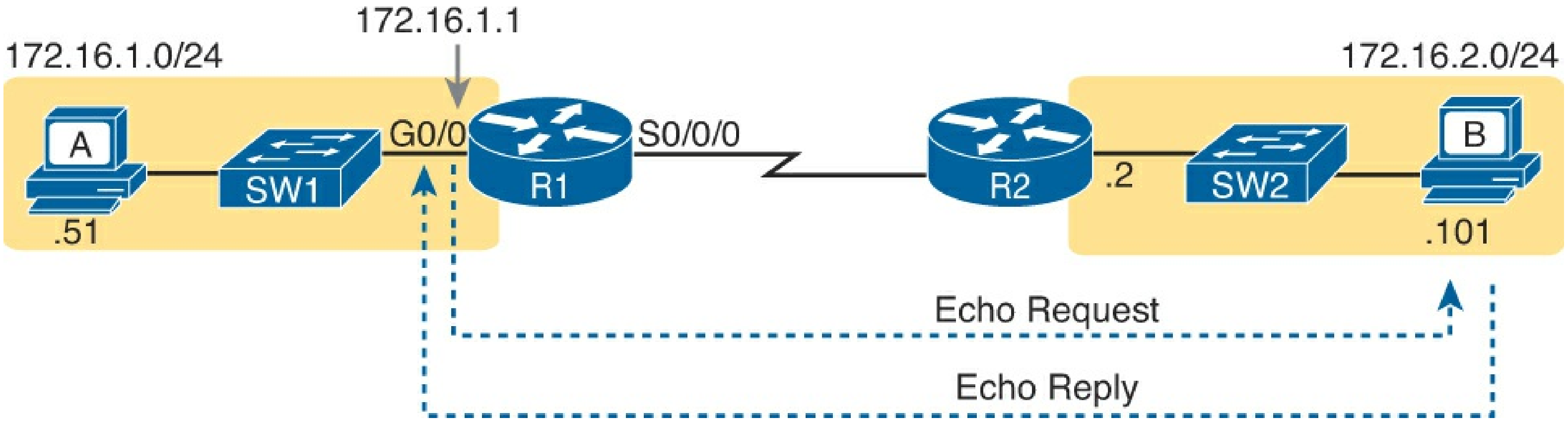

172.16.1.1
172.16.1.0/24
172.16.2.0/24
A
SW1
G0/0
R1
S0/0/0
R2
.2
SW2
B
.51
.101
Echo Request
Echo Reply

Figure 4-11. Extended Ping Command Tests the Route to 172.16.1.51

For review, take a look at how the router extended **ping** command works at the CLI. It allows the user to choose from several additional parameters on the **ping** command as compared to the standard **ping** command. While the extended **ping** command does allow the user to type all the parameters on a potentially long command, it also allows users to simply issue the **ping** command, press Enter, with IOS then asking the user to answer questions to complete the command, as shown in Example 4-3. The example shows the **ping** command on R1 that matches the logic in Figure 4-11.

Example 4-3. Testing the Reverse Route Using the Extended Ping

[Click here to view code image](#)

```
R1# ping
Protocol [ip]:
Target IP address: 172.16.2.101
Repeat count [5]:
Datagram size [100]:
Timeout in seconds [2]:
Extended commands [n]: y
Source address or interface: 172.16.1.1
Type of service [0]:
Set DF bit in IP header? [no]:
Validate reply data? [no]:
Data pattern [0xABCD]:
Loose, Strict, Record, Timestamp, Verbose[none]:
Sweep range of sizes [n]:
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.101, timeout is 2 seconds:
Packet sent with a source address of 172.16.1.1
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/2/4 ms
```

This particular extended **ping** command tests the same routes for the Echo Request going to the right, but it forces a better test of routes pointing back to the left for the ICMP Echo Reply. For that direction, R2 needs a route that matches address 172.16.1.1, which is likely to be a route for subnet 172.16.1.0/24—the same subnet in which host A resides.

From a troubleshooting perspective, using both standard and extended **ping** commands can be useful. However, neither can exactly mimic a **ping** command created on the host itself because the routers cannot send packets with the host's IP address. For instance, the extended **ping** in Example 4-3 uses source IP address 172.16.1.1, which is not host A's IP address. As a result, neither the standard or extended **ping** commands in these two examples so far in this chapter can test for some kinds of problems, such as the following:

- ACLs that discard packets based on host A's IP address, while that same ACL permits packets matched on the router's IP address
- LAN switch port security issues that filter A's packets (based on A's MAC address)
- IP routes on routers that happen to match the host A's 172.16.1.51 address, with different routes that match R1's 172.16.1.1 address
- Problems with host A's default router setting

Testing LAN Neighbors with Standard Ping

Testing using a **ping** of another device on the LAN can quickly confirm whether the LAN can pass packets and frames. Specifically, a working **ping** rules out many possible root causes of a problem, including all the Ethernet LAN features discussed in Chapter 3, "Troubleshooting LAN Switching." For instance, Figure 4-12 shows the ICMP messages that occur if from R1 the command **ping 172.16.1.51** is issued, pinging host A, which sits on the same VLAN as R1.

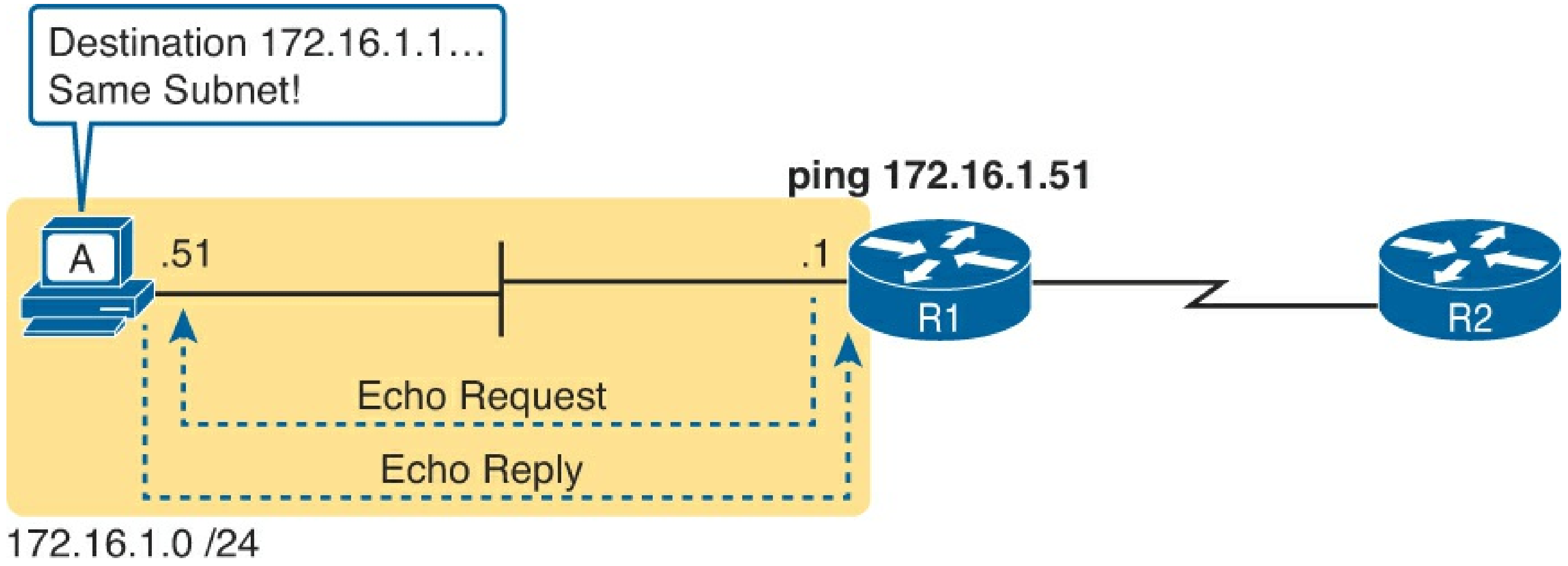


Figure 4-12. Standard ping **Command Confirms that the LAN Works**

If the ping works, it confirms the following, which rules out some potential issues:

- The host with address 172.16.1.51 replied.
- The LAN can pass unicast frames from R1 to host 172.16.1.51 and vice versa.
- You can reasonably assume that the switches learned the MAC addresses of the router and the host, adding those to the MAC address tables.
- Host A and router R1 completed the ARP process and list each other in their respective ARP tables.

If the **ping 172.16.1.51** on R1 fails, that result points to list of potential root causes, as well, including the following:

Key Topic

- Host A could be statically configured with the wrong IP address.
- If you are using Dynamic Host Configuration Protocol (DHCP), many problems could exist: Host A could be using a different IP address than 172.16.1.51, the DHCP configuration could be wrong, the routers may be missing the DHCP relay configuration and so host A never got its IPv4 address lease, and so on.
- The router could be configured for 802.1Q trunking, when the switch is not (or vice versa).
- Any LAN problem discussed in Part I of this book.

So, whether the ping works or fails, simply pinging a LAN host from a router can help further isolate the problem.

Testing LAN Neighbors with Extended Ping

A standard ping of a LAN host from a router does not test that host's default router setting. However, an extended ping can test the host's default router setting. Both tests can be useful, especially for problem isolation, because

Key Topic

- If a standard ping of a local LAN host works…
- But an extended ping of the same LAN host fails…
- The problem likely relates somehow to the host's default router setting.

First, to understand why the standard and extended ping results have different effects, consider first the standard **ping 172.16.1.51** command on R1, as shown previously in Figure 4-12. As a standard **ping** command, R1 used its LAN interface IP address (172.16.1.1) as the source of the ICMP Echo. So, when the host (A) sent back its ICMP Echo Reply, host A considered the destination of 172.16.1.1 as being on the same subnet. Host A's ICMP Echo Reply message, sent back to 172.16.1.1, would work even if host A did not have a default router setting at all!

In comparison, Figure 4-13 shows the difference when using an extended ping on router R1. An extended ping from local router R1, using R1's S0/0/0 IP address of 172.16.4.1 as the source of the ICMP Echo Request, means that host A's ICMP Echo Reply will flow to an address in another subnet, which makes host A use its default router setting.

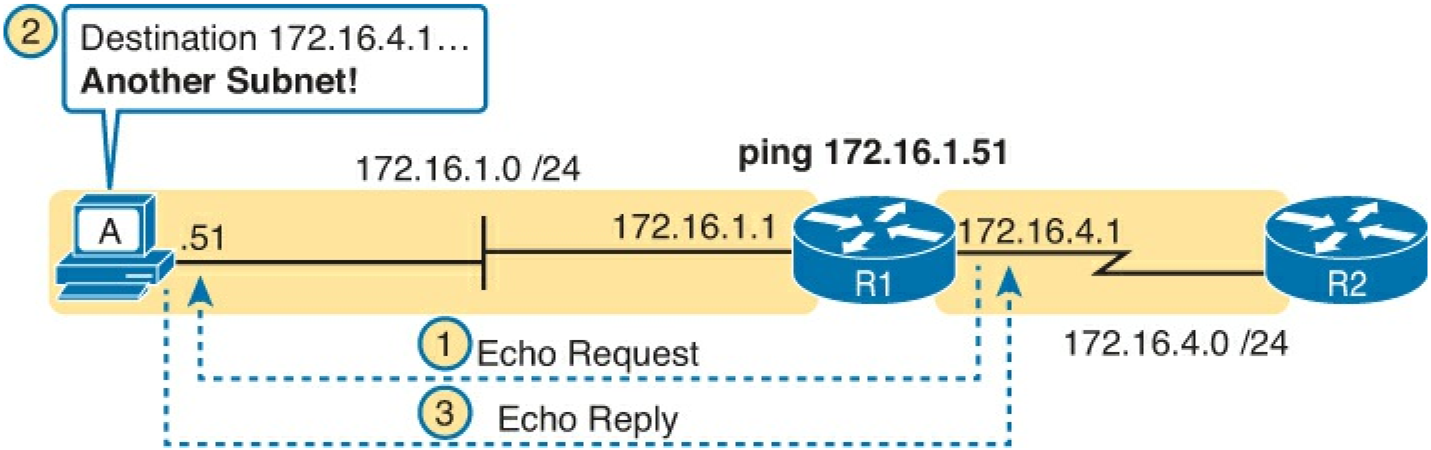


Figure 4-13. Extended ping **Command Does Test Host A's Default Router Setting**

The comparison between the previous two figures shows one of the most classic mistakes when troubleshooting networks. Sometimes, the temptation is to connect to a router and ping the host on the attached LAN, and it works. So, the engineer moves on, thinking that the network layer issues between the router and host work fine, when the problem still exists with the host's default router setting.

Testing WAN Neighbors with Standard Ping

As with a standard ping test across a LAN, a standard ping test between routers over a serial WAN link tests whether the link can pass IPv4 packets. With a properly designed IPv4 addressing plan, two routers on the same serial link should have IP addresses in the same subnet. A ping from one router to the serial IP address of the other router confirms that an IP packet can be sent over the link and back, as shown in the **ping 172.16.4.2** command on R1 in Figure 4-14.

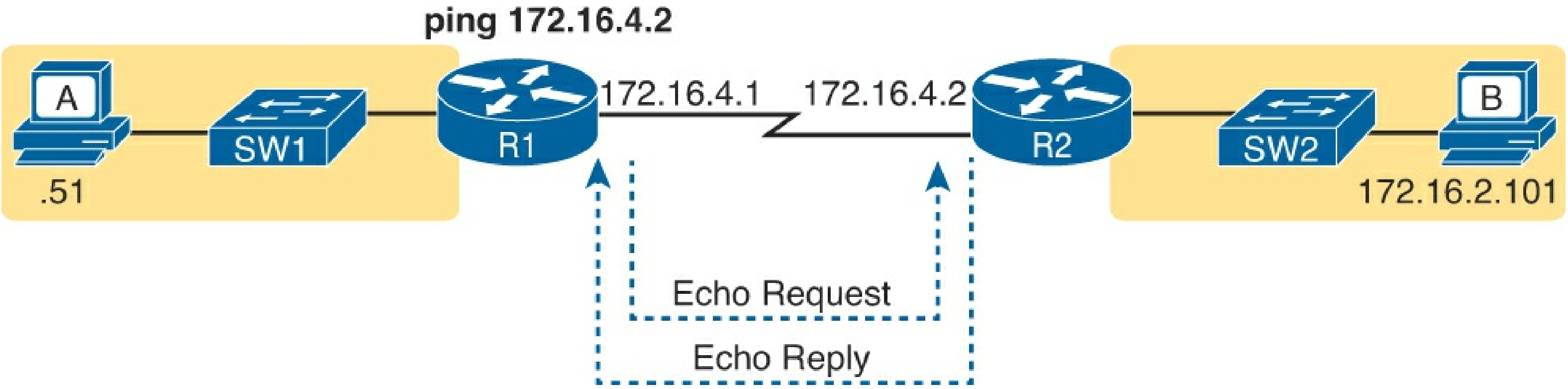


Figure 4-14. Pinging Across a WAN Link

Key Topic

If the ping works, it confirms some specific facts:

- Both router's serial interfaces are in an up/up state.
- The Layer 1 and 2 features of the link work.
- The routers believe that the neighboring router's IP address is in the same subnet.
- Inbound ACLs on both routers do not filter the incoming packets, respectively.
- The remote router is configured with the expected IP address (172.16.4.2 in this case).

If this ping test fails, use this same list to help find the root cause. For instance, connect to the routers' CLI and do a quick check of the routers' interface states and IP address/mask combinations. Then, for Layer 1 and 2 issues, use the details discussed in Chapter 12, "Implementing Point-to-Point WANs."

Testing by pinging the other neighboring router does not test many other features, though. For instance, pinging the neighboring router's serial IP address only tests one route on each router: the connected route to the subnet on the serial link. This ping does not test any routes for subnets on LANs. Also, neither the source or destination IP address matches the two hosts that have the original problem, so this test does not do much to help find issues with ACLs. However, although the test is limited in scope, it does let you rule out WAN links as having a Layer 1 or 2 problem, and it rules out some basic Layer 3 addressing problems.

Using Ping with Names and with IP Addresses

All the ping examples so far in this chapter show a ping of an IP address. However, the **ping** command can use hostnames, and pinging a hostname allows the network engineer to further test whether the Domain Name System (DNS) process works.

First, most every TCP/IP application today uses hostnames rather than IP addresses to identify the other device. No one opens a web browser and types in http://72.163.4.161/. Instead, they type in a web address, like http://www.cisco.com, which includes the hostname www.cisco.com. Then, before a host can send data to a specific IP address, the host must first ask a DNS server to resolve that hostname into the matching IP address.

For example, in the small internetwork used for several examples in this chapter, a **ping B** command on host A tests A's DNS settings, as shown in Figure 4-15. When host A sees the use of a hostname (B), it first looks in its local DNS name cache to find out whether it has already resolved the name B. If not, host A first asks the DNS to supply (resolve) the name into its matching IP address (Step 1 in the figure). Only then does host A send a packet to 172.16.2.101, host B's IP address (Step 2).

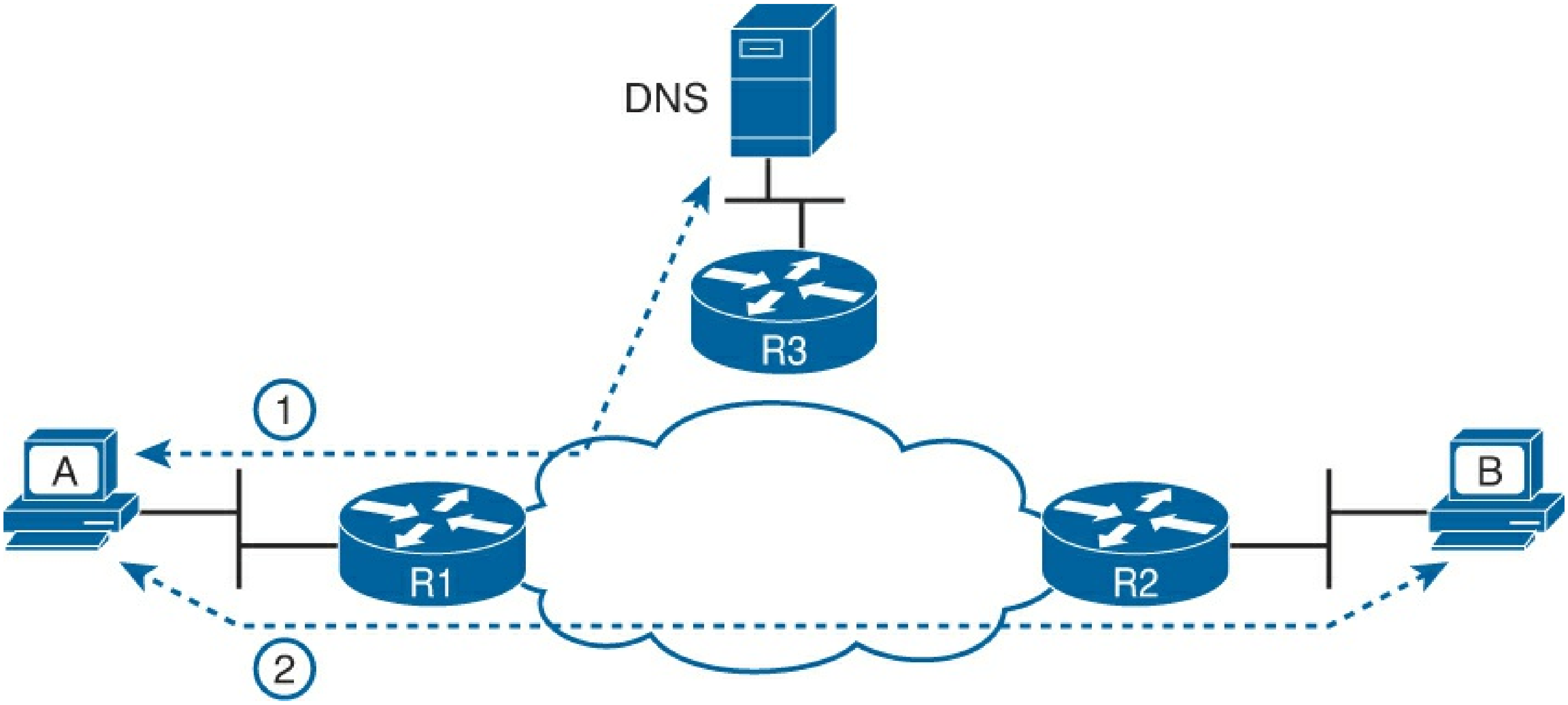


Figure 4-15. DNS Name Resolution by Host A

When troubleshooting, testing from the host by pinging using a hostname can be very helpful. The command, of course, tests the host's own DNS client settings. For instance, a classic comparison is to first ping the destination host using the hostname, which requires a DNS request. Then, repeat the same test, but use the destination host's IP address instead of its name, which does not require the DNS request. If the ping of the hostname fails but the ping of the IP address works, the problem usually has something to do with DNS.

Problem Isolation Using the traceroute Command

Like **ping**, the **traceroute** command helps network engineers isolate problems. Here is a comparison of the two:

Key Topic

- Both send messages in the network to test connectivity.
- Both rely on other devices to send back a reply.
- Both have wide support on many different operating systems.
- Both can use a hostname or an IP address to identify the destination.
- On routers, both have a standard and extended version, allowing better testing of the reverse route.

The biggest differences relate to the more detailed results in the output of the **traceroute** command and the extra time and effort it takes **traceroute** to build that output. This third of three major sections examines how traceroute works, plus some suggestions of how to use this more detailed information to more quickly isolate IP routing problems.

traceroute Basics

Imagine some network engineer or CSR starts to troubleshoot some problem. They **ping** from the user's host, **ping** from a nearby router, and after a few commands, convince themselves that the host can indeed send and receive IP packets. The problem might not be solved yet, but the problem does not appear to be a network problem.

Now imagine the next problem comes along, and this time the **ping** command fails. It appears that some problem does exist in the IP network. Where is the problem? Where should the engineer look more closely? Although **ping** can prove helpful in isolating the source of the problem, the **traceroute** command may be a better option. The **traceroute** command systematically helps pinpoint routing problems by showing how far a packet goes through an IP network before being discarded.

The **traceroute** command identifies the routers in the path from source host to destination host. Specifically, it lists the next-hop IP address of each router that would be in each of the individual routes. For instance, a **traceroute 172.16.2.101** command on host A in Figure 4-16 would identify an IP address on router R1, another on router R2, and then host B, as shown in the figure. Example 4-4 that follows lists the output of the command, taken from host A.

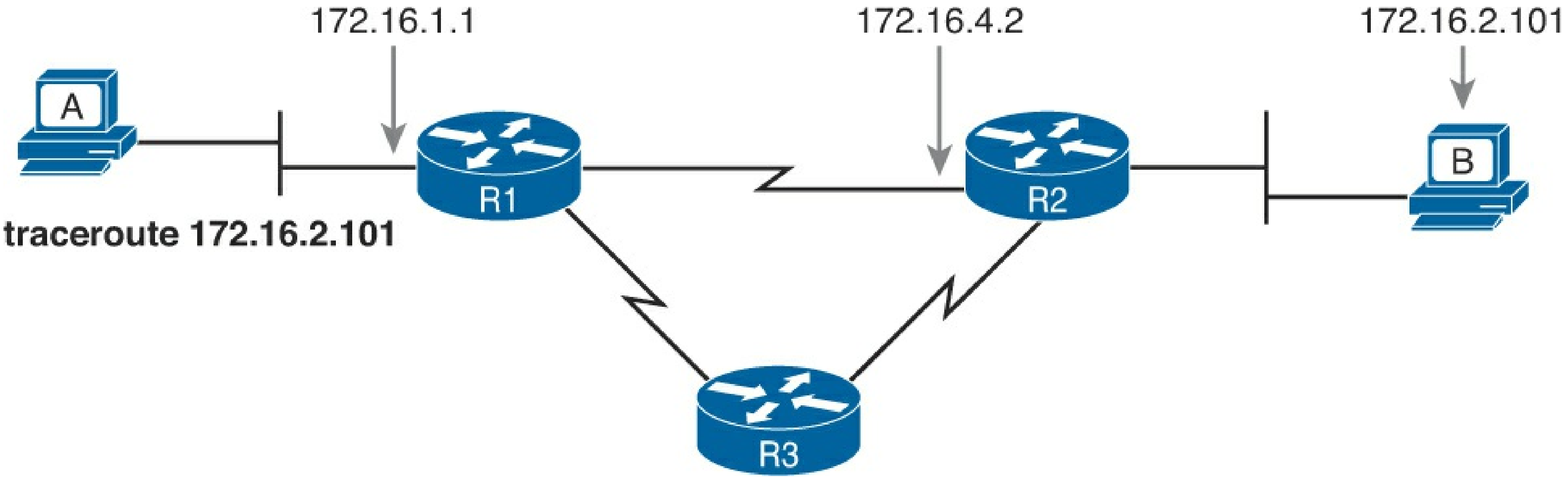


Figure 4-16. IP Addresses Identified by a Successful traceroute 172.16.2.101 **Command on Host A**

Example 4-4. Output from traceroute 172.16.2.101 **on Host A**

Click here to view code image

```
WendellOdoms-iMac:~ wendellodom$traceroute 172.16.2.101
traceroute to 172.16.2.101, 64 hops max, 52 byte packets
1 172.16.1.1 (172.16.1.1) 0.870 ms 0.520 ms 0.496 ms
2 172.16.4.2 (172.16.4.2) 8.263 ms 7.518 ms 9.319 ms
3 172.16.2.101 (172.16.2.101) 16.770 ms 9.819 ms 9.830 ms
```

How the traceroute Command Works

The **traceroute** command gathers information by generating packets that trigger error messages from routers; these messages identify the routers, letting the **traceroute** command list the routers' IP addresses in the output of the command. That error message is the ICMP Time-to-Live Exceeded (TTL Exceeded) message, originally meant to notify hosts when a packet had been looping around a network.

IPv4 routers defeat routing loops in part by discarding looping IP packets. To do so, the IPv4 header holds a field called Time To Live (TTL). The original host that creates the packet sets an initial TTL value. Then, each router that forwards the packet decrements the TTL value by 1. When a router decrements the TTL to 0, the router perceives the packet is looping, and the router discards the packet. The router also notifies the host that sent the discarded packet by sending an ICMP TTL Exceeded message.

Now back to traceroute. Traceroute sends messages with low TTL values, to make the routers send back a TTL Exceeded message. Specifically, a **traceroute** command begins by sending several packets (usually three), each with the header TTL field equal to 1. When that packet arrives at the next router—host A's default router R1 in the example of Figure 4-17—the router decrements TTL to 0 and discards the packet. The router then sends host A the TTL Exceeded message, which identifies the router's IP address to the **traceroute** command.

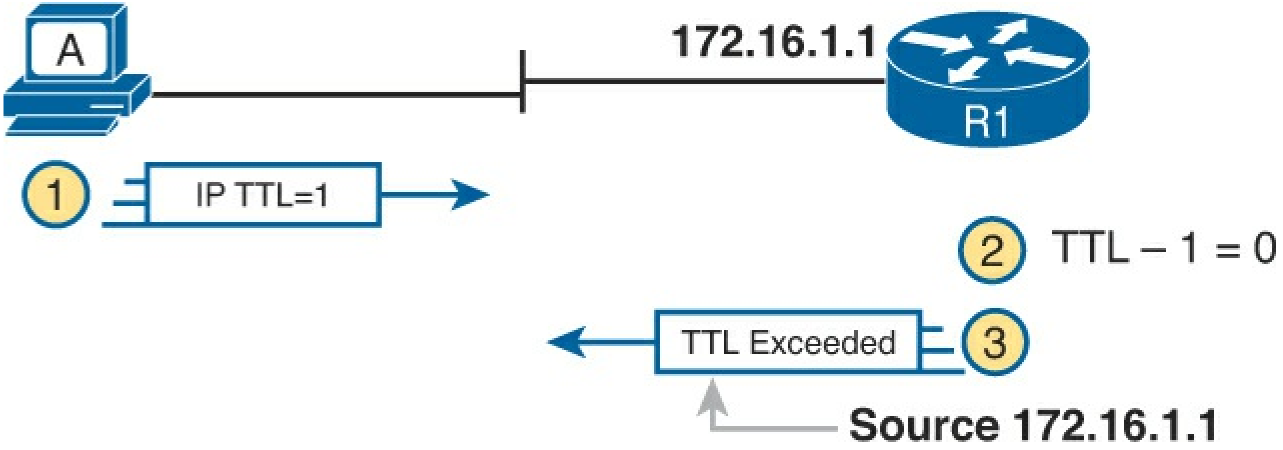


Figure 4-17. How traceroute **Identifies the First Router in the Route**

The **traceroute** command sends several TTL=1 packets, checking them to see whether the TTL Exceeded messages flow from the same router, based on the source IP address of the TTL Exceeded message. Assuming the messages come from the same router, the **traceroute** command lists that IP address as the next line of output on the command. Routers have a choice of IP addresses to use, but as you might guess at this point, routers use the IP address of the outgoing interface. In this case, R1's outgoing interface for the TTL Exceeded message is 172.16.1.1.

To find all the routers in the path, and finally confirm that packets flow all the way to the destination host, the **traceroute** command sends packet with TTL=1, TTL=2, then 3, 4, and so on, until the destination host replies. Figure 4-18 shows the packet from the second set with a TTL=2. In this case, one router (R1) actually forwards the packet, while another router (R2) happens to decrement the TTL to 0, causing a TTL Exceeded message being sent back to host A.

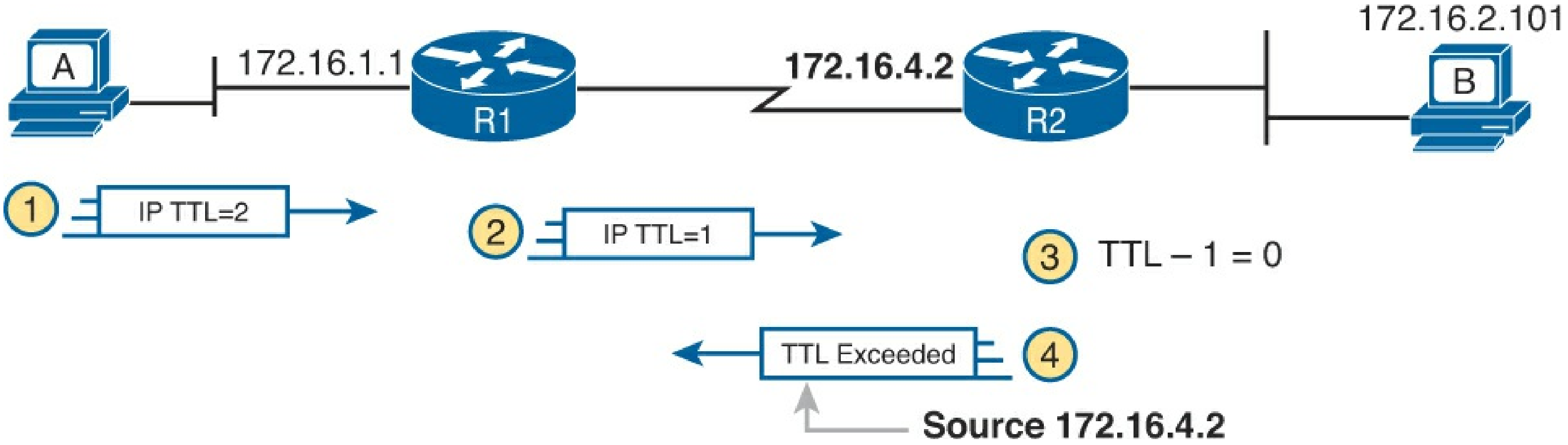


Figure 4-18. TTL=2 Message Sent by traceroute

The figure shows these four steps:

1. The **traceroute** command sends a packet from the second set with TTL=2.
2. Router R1 processes the packet and decrements TTL to 1. R1 forwards the packet.
3. Router R2 processes the packet and decrements TTL to 0. R2 discards the packet.
4. R2 notifies the sending host of the discarded packet by sending a TTL Exceeded ICMP message. The source IP address of that message is R2’s outgoing interface for the message (in this case, 172.16.4.2).

Standard and Extended traceroute

The standard and extended options for the **traceroute** command give you many of the same options as the **ping** command. For instance, Example 4-5 lists the output of a standard **traceroute** commands on router R1. Like the standard **ping** command, a standard **traceroute** command chooses an IP address based on the outgoing interface for the packet sent by the command. So, in this example, the packets sent by R1 come from source IP address 172.16.4.1, R1’s S0/0/0 IP address.

Example 4-5. Standard traceroute **on R1**

Click here to view code image

```
R1# traceroute 172.16.2.101
Type escape sequence to abort.
Tracing the route to 172.16.2.101
VRF info: (vrf in name/id, vrf out name/id)
1 172.16.4.2 0 msec 0 msec 0 msec
2 172.16.2.101 0 msec 0 msec *
```

The extended **traceroute** command, as shown in Example 4-6, follows the same basic command structure as the extended **ping** command. The user can type all the parameters on one command line, but it is much easier to just type **traceroute**, press Enter, and let IOS prompt for all the parameters, including the source IP address of the packets (172.16.1.1 in this example).

Example 4-6. Extended traceroute **on R1**

Click here to view code image

```
R1# traceroute
Protocol [ip]:
Target IP address: 172.16.2.101
Source address: 172.16.1.1
Numeric display [n]:
Timeout in seconds [3]:
Probe count [3]:
Minimum Time to Live [1]:
Maximum Time to Live [30]:
Port Number [33434]:
Loose, Strict, Record, Timestamp, Verbose[none]:
Type escape sequence to abort.
Tracing the route to 172.16.2.101
VRF info: (vrf in name/id, vrf out name/id)
1 172.16.4.2 0 msec 0 msec 0 msec
```

```
 2 172.16.2.101 0 msec 0 msec *
```

Both the **ping** and **traceroute** commands exist on most operating systems, including Cisco IOS. However, some operating systems use a slightly different syntax for traceroute. For example, most Windows operating systems support **tracert** and **pathping**, and not **traceroute**. Linux and OS X support the **traceroute** command.

> **Note**
>
> Host OS **traceroute** commands usually create ICMP Echo Requests. The Cisco IOS **traceroute** command instead creates IP packets with a UDP header. This bit of information may seem trivial at this point. However, note that an ACL may actually filter the traffic from a host's **traceroute** messages but not the router **traceroute** command, or vice versa.

Using traceroute to Isolate the Problem to Two Routers

One of the best features of the **traceroute** command, as compared to ping, is that when it does not complete it gives an immediate clue as to where to look next. With ping, when the ping fails, the next step is usually to use more **ping** commands. With **traceroute**, it tells you what router to try and connect and look at the routes and in which direction.

> **Note**
>
> As a reminder, this term uses the term *forward route* for routes that send the packets sent by the **ping** or **traceroute** command, and *reverse route* for the packets sent back.

When a problem exists, a **traceroute** command results in a partial list of routers. Then the command either finishes with an incomplete list or it runs until the user must stop the command. In either case, the output does not list all routers in the end-to-end route, because of the underlying problem.

> **Note**
>
> In addition, the **traceroute** command may not finish even though the network has not problems. Routers and firewalls may filter the messages sent by the **traceroute** command, or the TTL Exceeded messages, which would prevent the display of portions or all or part of the path.

The last router listed in the output tells us where to look next, as follows:

Key Topic

- Connect to the CLI of the last router listed, to look at forward route issues.
- Connect to the CLI of the next router that should have been listed, to look for reverse route issues.

To see why, consider an example based on the internetwork in Figure 4-19. In this case, R1 uses an extended traceroute to host 5.5.5.5, with source IP address 1.1.1.1. This command's output lists router 2.2.2.2, then 3.3.3.3, and then the command cannot complete.

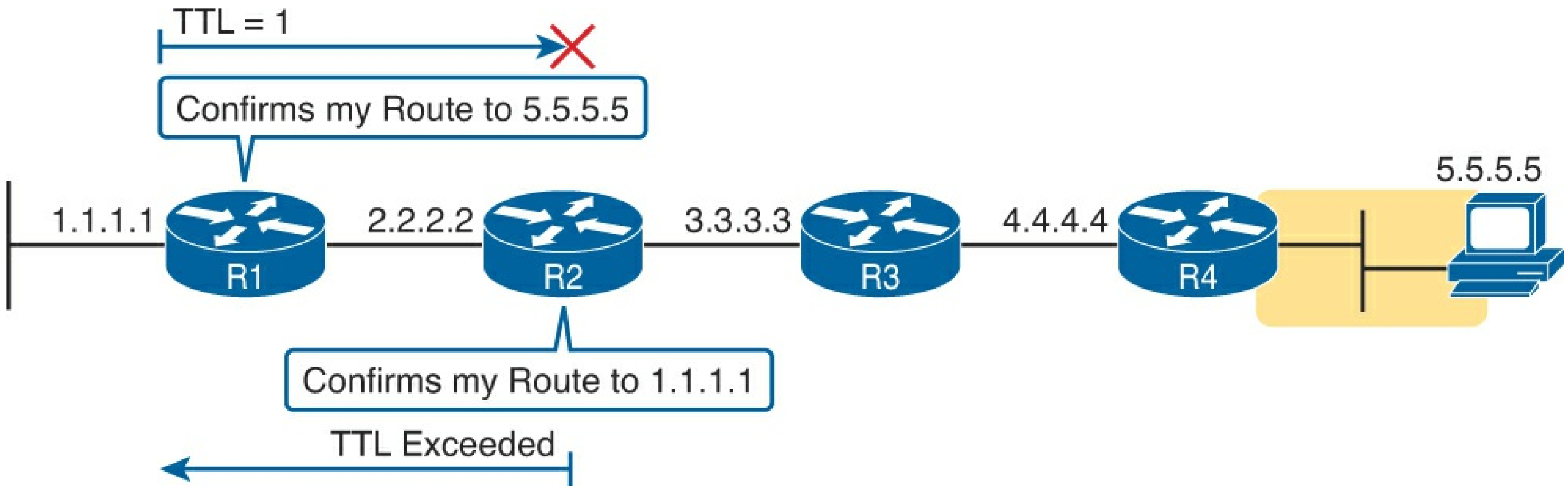


Figure 4-19. Messages That Cause the traceroute **Command to List 2.2.2.2**

First, Figure 4-19 focuses on the first line of output: the line that lists first-hop router 2.2.2.2.

The figure shows the TTL=1 message at the top and the TTL Exceeded message back on the bottom. This first pair of messages in the figure must have worked, because without them, the **traceroute** command on R1 cannot have learned about a router with address 2.2.2.2. The first (top) message required R1 to have a route for 5.5.5.5, which sent the packets to R2 next. The TTL Exceeded message required that R2 have a route that matched address 1.1.1.1, to send the packets back to R1's LAN IP address.

Next, Figure 4-20 focuses on the messages that allow the second line of output on R1's sample **traceroute** command: the line that correctly lists 3.3.3.3 as the next router in the route.

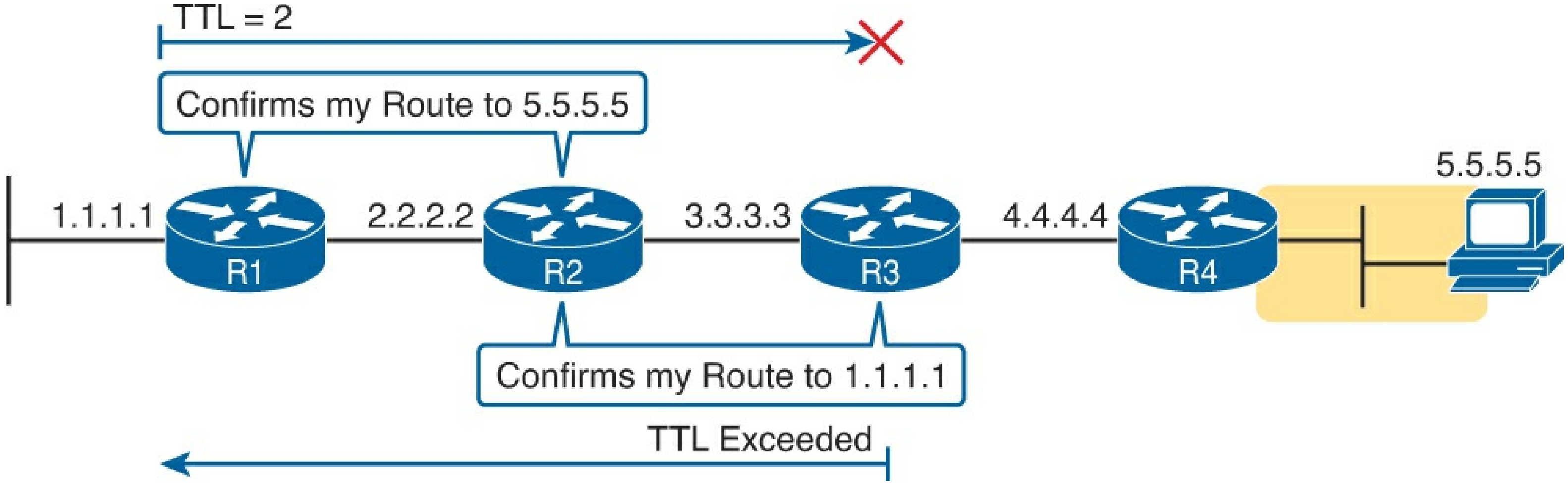

TTL = 2
Confirms my Route to 5.5.5.5
5.5.5.5
1.1.1.1
R1
2.2.2.2
R2
3.3.3.3
R3
4.4.4.4
R4
Confirms my Route to 1.1.1.1
TTL Exceeded

Figure 4-20. Messages That Cause the traceroute **Command to List 3.3.3.3**

Following the same logic, the **traceroute** output lists 3.3.3.3 because the messages in Figure 4-20 must have worked. For these messages to flow, the routes listed in Figure 4-19 must exist, plus new routes listed in Figure 4-20. Specifically, the TTL=2 packet at the top requires R2 to have a route for 5.5.5.5, which sends the packets to R3 next. The TTL Exceeded message requires that R3 have a route that matches address 1.1.1.1, to send the packets back toward R1's LAN IP address.

In this example, the **traceroute 5.5.5.5** command does not list any routers beyond 2.2.2.2 and 3.3.3.3 However, based on the figures, it is clear that 4.4.4.4 should be the next IP address listed. To help isolate the problem further, why might the next messages—the message with TTL=3 and the response—fail?

Figure 4-21 points out the routing issues that can cause this command to not be able to list 4.4.4.4 as the next router. First, R3 must have a forward route matching destination 5.5.5.5 and forwarding the packet to router R4. The return message requires a reverse route matching destination 1.1.1.1 and forwarding the packet back to router R3.

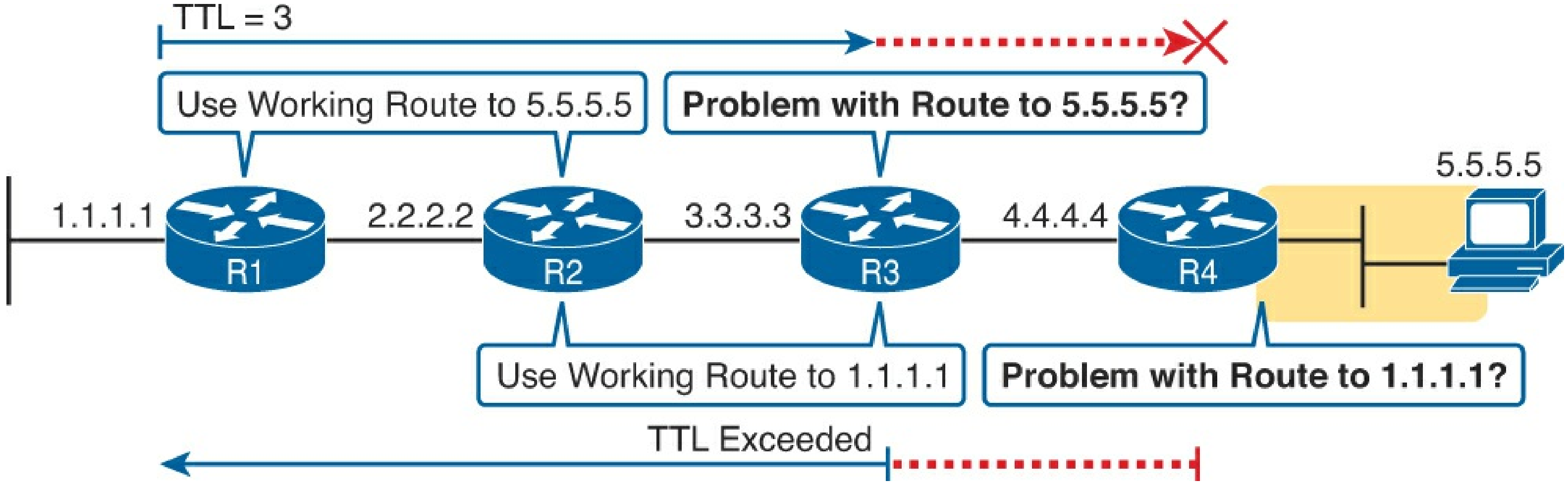

TTL = 3
Use Working Route to 5.5.5.5
Problem with Route to 5.5.5.5?
5.5.5.5
1.1.1.1
R1
2.2.2.2
R2
3.3.3.3
R3
4.4.4.4
R4
Use Working Route to 1.1.1.1
Problem with Route to 1.1.1.1?
TTL Exceeded

Figure 4-21. Messages That Could Have Caused traceroute **to List 4.4.4.4**

In conclusion, for this example, if a routing problem prevents the **traceroute** command from working, the problem exists in one of two places: the forward route to 5.5.5.5 on router R3, or the reverse route to 1.1.1.1 on R4.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 4-1 lists these key topics and where each is discussed.

Key Topic

Table 4-1. Key Topics for Chapter 4

Key Topic Element	Description	Page Number
List	Host routing logic	133
List	Router routing logic	134
Figure 4-3	Router routing logic	135
Figure 4-4	Router deencapsulation and encapsulation end to end through an internetwork	136
Figure 4-5	ARP example and concept	137
Figure 4-10	ARP tables on Layer 3 hosts, with MAC address tables on Layer 2 switch	142
Figure 4-11	How extended ping in IOS performs a better test of the reverse route	143
List	Types of root causes of host connectivity problems that cannot be found by router **ping** commands	143
Figure 4-12	Why a standard ping over a LAN does not exercise a host's default router logic	144
List	Network layer problems that could cause a ping to fail between a router and host on the same LAN subnet	144
List	Testing a host's default router setting using extended ping	145
List	Items confirmed as working when pinging the router IP address on the other end of a serial link	146
List	Comparisons between the **ping** and **traceroute** commands	147
List	The two places to look for routing problems when a **traceroute** command does not complete	151

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22 directs you in how to use these terms for late-stage preparation for the exam.

encapsulation
deencapsulation
default router
ARP
ping
traceroute
ICMP Echo Request
ICMP Echo Reply
extended ping
forward route
reverse route
DNS

Chapter 5. Troubleshooting IPv4 Routing Part II

This chapter covers the following exam topics:

Troubleshooting

- Identify and correct common network problems
- Troubleshoot and resolve interVLAN routing problems
  - Connectivity
  - Encapsulation
  - Subnet
  - Native VLAN
  - Port mode trunk status
- Troubleshoot and resolve routing issues
  - routing is enabled
  - routing table is correct
  - correct path selection

Chapter 4, "Troubleshooting IPv4 Routing Part I," began the discussion of IPv4 troubleshooting, looking at the usual first steps when troubleshooting a problem. This chapter moves on to a later stage, when the problem has been isolated to a smaller part of the network, and to a smaller set of possible causes of the problem. The topics in this chapter get specific and look for those root causes: the causes of network problems that have specific solutions that, once a change is made, will solve the original problem.

This chapter breaks down the discussion based on the two major divisions in how packets are forwarded in an IPv4 internetwork. The first half of the chapter focuses on the root causes of problems between a host and its default router. The second half looks at the routers that forward the packet over the rest of a packet's journey, from the router acting as default router all the way to the destination host.

Note that in addition to Chapters 4 and 5, other chapters in this book discuss troubleshooting topics that help when troubleshooting IPv4 internetworks. In particular, Chapter 11, "Troubleshooting IPv4 Routing Protocols," discusses troubleshooting IPv4 routing protocols, namely Open Shortest Path First (OSPF) and Enhanced Interior Gateway Routing Protocol (EIGRP). Chapter 3, "Troubleshooting LAN Switching," discussed how to troubleshoot LAN issues. Some topics inside the chapters in Part IV explain how to troubleshoot WAN links. Finally, Chapter 16, "Troubleshooting IPv6 Routing," discusses how to apply these same IPv4 troubleshooting concepts to IPv6.

"Do I Know This Already?" Quiz

The troubleshooting chapters of this book pull in concepts from many other chapters, including some chapters in *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*. They also show you how to approach some of the more challenging questions on the CCNA exams. Therefore, it is useful to read these chapters regardless of your current knowledge level. For these reasons, the troubleshooting chapters do not include a "Do I Know This Already?" quiz. However, if you feel particularly confident about troubleshooting IP routing features covered in this book and *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*, feel free to move to the "Exam Preparation Tasks" section near the end of this chapter to bypass the majority of the chapter.

Foundation Topics

Problems Between the Host and the Default Router

Imagine that you work as a customer support rep (CSR) fielding calls from users about problems. A user left a message stating that he couldn't connect to a server. You could not reach him when you called back, so you did a series of pings from that host's default router, using some of the problem isolation strategies described in Chapter 4. And at the end of those pings, you think the problem exists somewhere between the user's device and the default router—for instance, between router R1 and host A, as shown in Figure 5-1.

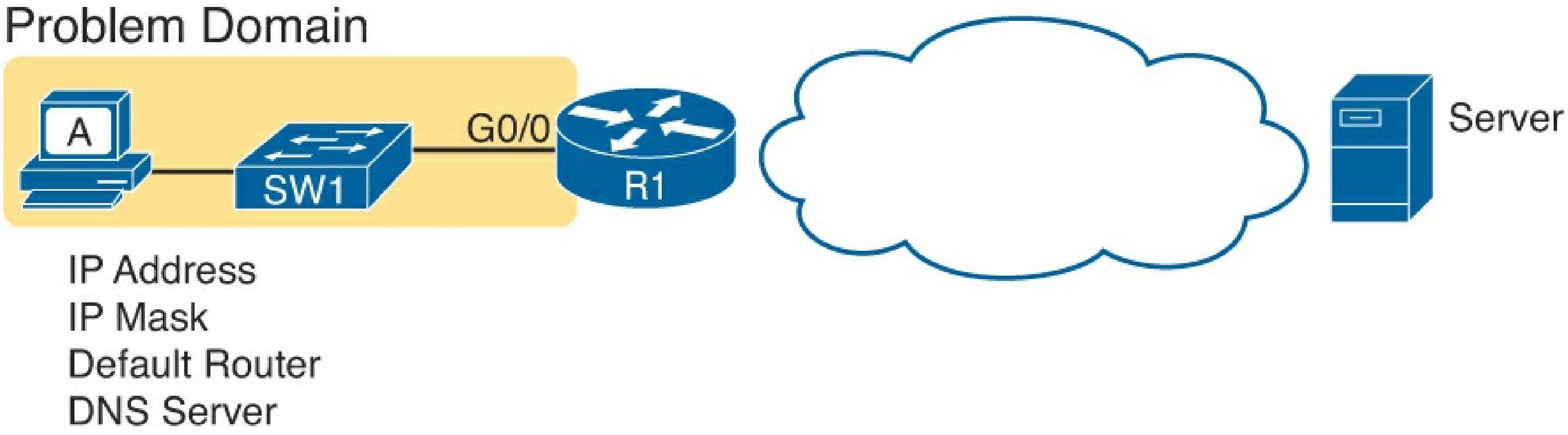


Figure 5-1. Focus of the Discussions in This Section of the Chapter

This first major section of the chapter focuses on problems that can occur on hosts, their default routers, and between the two. To begin, this section looks at the host itself, and its four IPv4 settings, as listed in the figure. Following that, the discussion moves to the default router, with focus on the LAN interface, and the settings that must work for the router to serve as a host's default router.

Root Causes Based on a Host's IPv4 Settings

A typical IPv4 host gets its four key IPv4 settings in one of two ways: either through static configuration or by using DHCP. In both cases, the settings can actually be incorrect. Clearly, any static settings can be set to a wrong number just through human error when typing the values. More surprising is the fact that the DHCP can set the wrong values: The DHCP process can work, but with incorrect values configured at the DHCP server, the host can actually learn some incorrect IPv4 settings.

This section first reviews the settings on the host, and what they should match, followed by a discussion of typical issues.

Ensure IPv4 Settings Correctly Match

Once an engineer thinks that a problem exists somewhere between a host and its default router, the engineer should review of the host's IPv4 settings versus the intended settings. That process begins by guiding the user through the GUI of the host operating system or by using command-line commands native to host operating systems, such as **ipconfig** and **ifconfig**. This process should uncover obvious issues, like completely missing parameters, or if using DHCP, the complete failure of DHCP to learn any of the IPv4 settings.

If the host has all its settings, the next step is to check the values to match them with the rest of the internetwork. The Domain Name System (DNS) server IP address—usually a list of at least two addresses—should match the DNS server addresses actually used in the internetwork. The rest of the settings should be compared to the correct LAN interface on the router that is used as this host's default router. Figure 5-2 collects all the pieces that should match, with some explanation to follow.

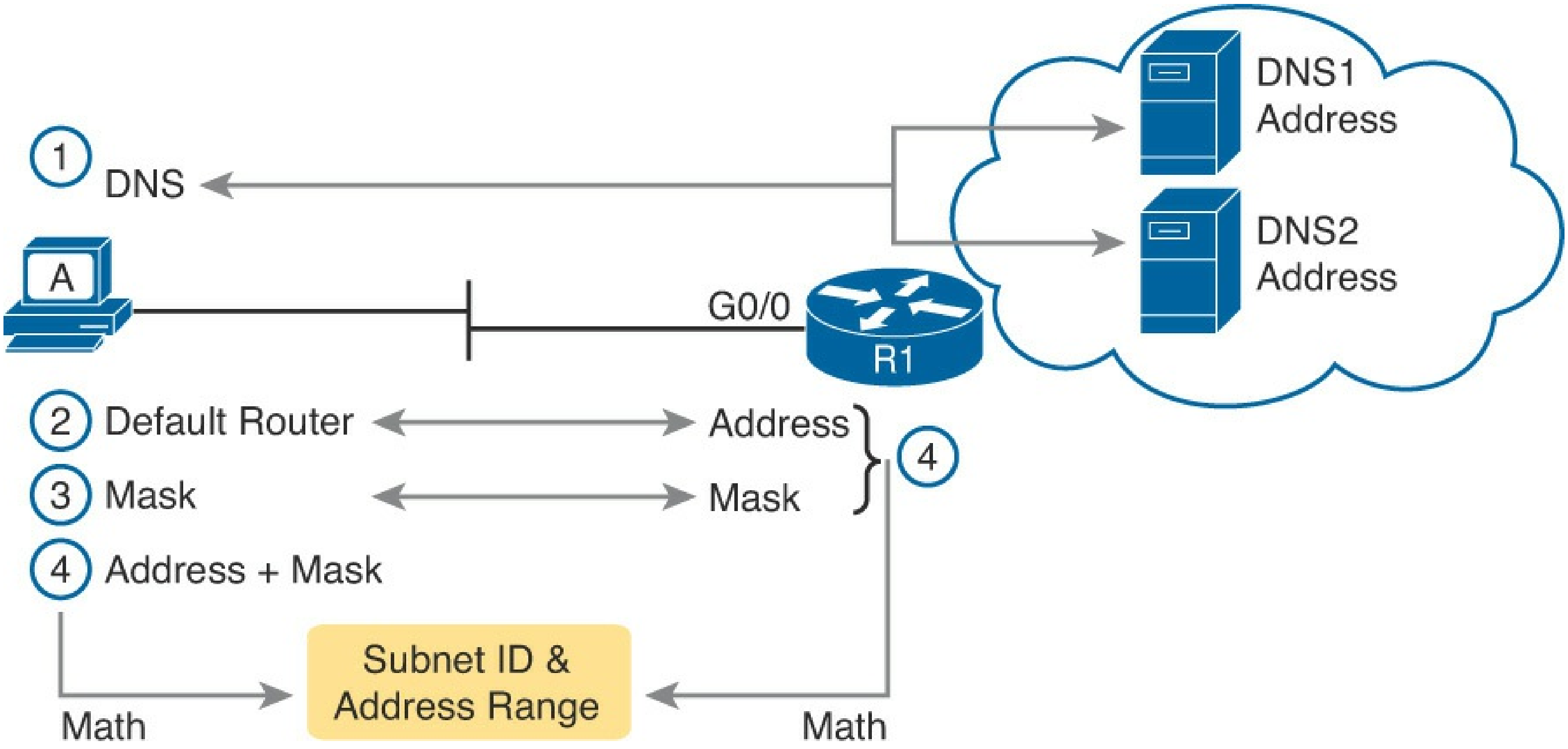


Figure 5-2. Host IPv4 Settings Compared to What the Settings Should Match

As numbered in the figure, these steps should be followed to check the host's IPv4 settings:

Step 1. Check the host's list of DNS server addresses against the actual addresses used by those servers.

Step 2. Check the host's default router setting against the router's LAN interface configuration, for the **ip address** command.

Step 3. Check the subnet mask used by the router and the host; if they use a different mask, the subnets will not exactly match, which will cause problems for some host addresses.

Step 4. The host and router should attach to the exact same subnet—same subnet ID and same range of IP addresses. So, use both the router's and host's IP address and mask, calculate the subnet ID and range of addresses, and confirm they are in the same subnet as the subnet implied by the address/mask of the router's **ip address** command.

If an IPv4 host configuration setting is missing, or simply wrong, checking these settings can quickly uncover the root cause. For instance, if you can log in to the router and do a **show interfaces G0/0** command, and then ask the user to issue an **ipconfig /all** (or similar) command and read the output to you, you can compare all the settings in Figure 5-2.

However, although checking the host settings is indeed very useful, some problems related to hosts are not so easy to spot. The next few topics walk through some example problems to show some symptoms that occur when some of these less obvious problems occur.

Mismatched Masks Impact Route to Reach Subnet

A host and its default router should agree about the range of addresses in the subnet. Sometimes, people are tempted to skip over this check, ignoring the mask either on the host or the router and assuming that the mask used on one device must be the same mask as on the other device. However, if the host and router have different subnet mask values, and therefore each calculates a different range of addresses in the subnet, problems happen.

To see one such example, consider the network in Figure 5-3. Host A has IP address/mask 10.1.1.9/24, with default router 10.1.1.150. Some quick math puts 10.1.1.150—the default router address—inside host A's subnet, right? Indeed it does, and it should. Host A's math for this subnet reveals subnet ID 10.1.1.0, with a range of addresses from 10.1.1.1 through 10.1.1.254, and subnet broadcast address 10.1.1.255.

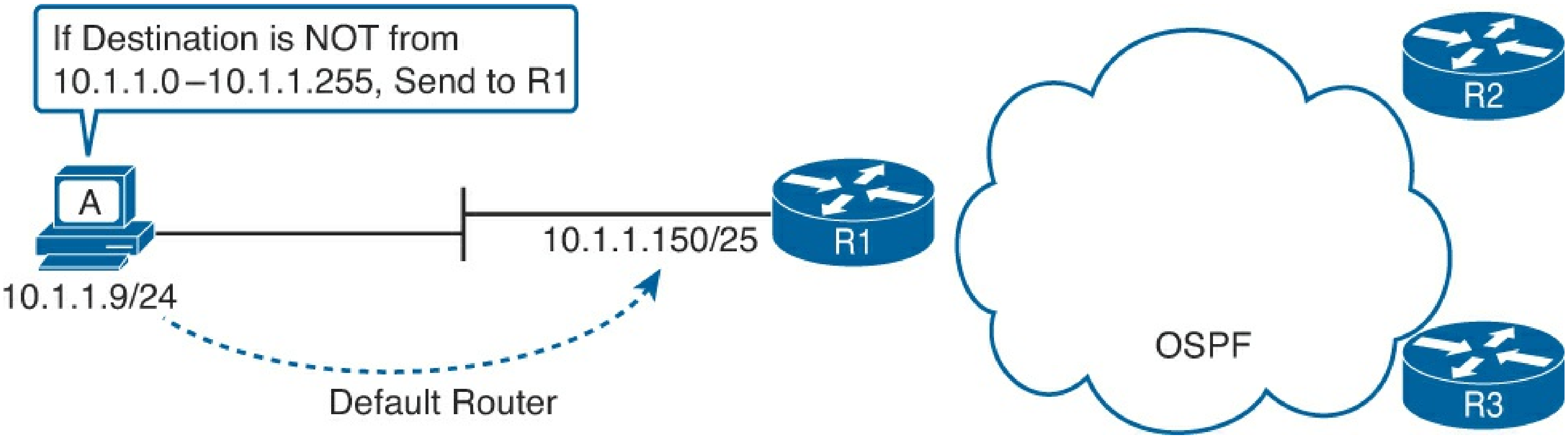


Figure 5-3. Mismatched Subnet Calculations Appear Workable from Host Toward Network

In this case, the host routing of packets, to destinations outside the subnet, works well. However, the reverse direction, from the rest of the network back toward the host, does not. A quick check of router R1's configuration reveals the IP address/mask as shown in Figure 5-3, which results in the connected route for subnet 10.1.1.128/25, as shown in Example 5-1.

Example 5-1. R1's IP Address, Mask, Plus the Connected Subnet That Omits Host A's Address

Click here to view code image

```
R1# show running-config interface g0/0
Building configuration...

Current configuration : 185 bytes
!
interface GigabitEthernet0/0
description LAN at Site 1
mac-address 0200.0101.0101
ip address 10.1.1.150 255.255.255.128
ip helper-address 10.1.2.130
duplex auto
speed auto
end

R1# show ip route connected
! Legend omitted for brevity

10.0.0.0/8 is variably subnetted, 9 subnets, 4 masks
C 10.1.1.128/25 is directly connected, GigabitEthernet0/0
```

```
L 10.1.1.150/32 is directly connected, GigabitEthernet0/0
! Other routes omitted for brevity
```

Because of this particular mismatch, R1's view of the subnet puts host A (10.1.1.9) outside R1's view of the subnet (10.1.1.128/25, range 10.1.1.129 to 10.1.1.254). R1 adds a connected route for subnet 10.1.1.128/25 into R1's routing table, and even advertises this route (with OSPF in this case) to the other routers in the network, as seen in Figure 5-4. All the routers know how to route packets to subnet 10.1.1.128/25, but unfortunately, that route does not include host A's 10.1.1.9 IP address.

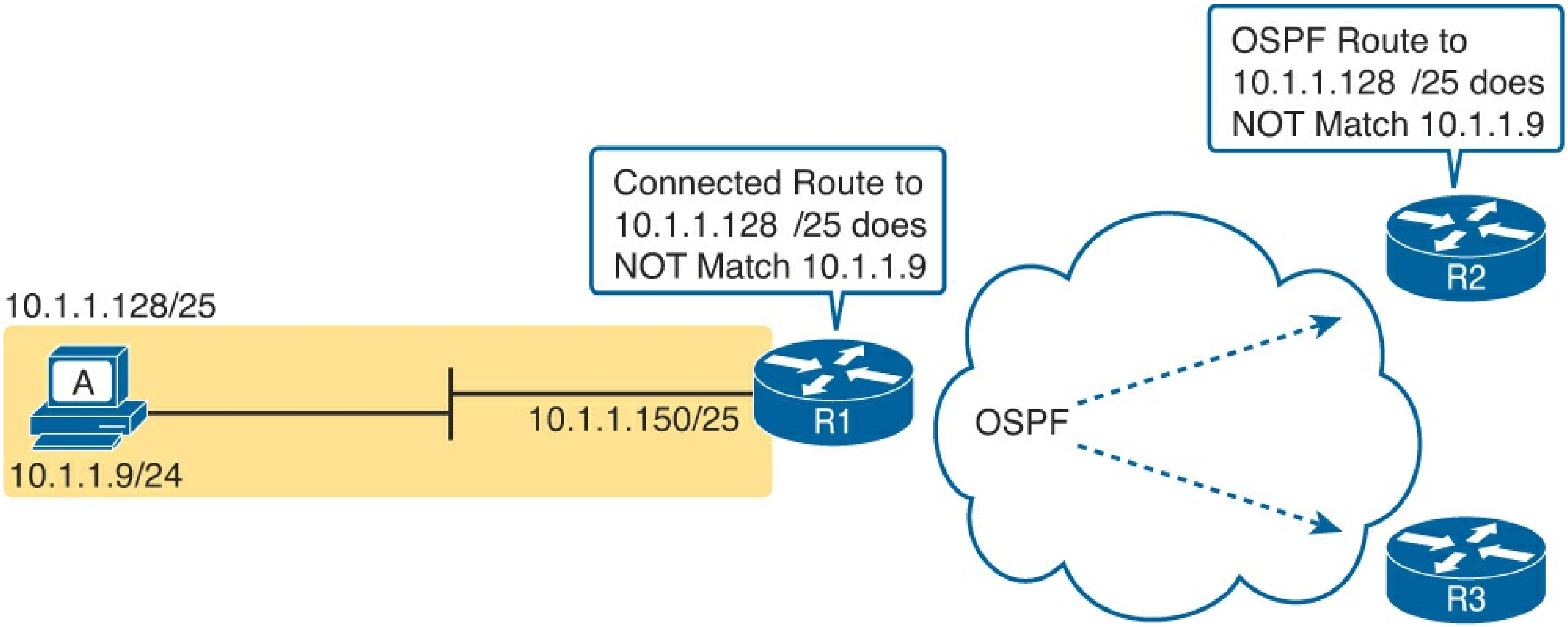


Figure 5-4. Routers Have No Route That Matches Host A's 10.1.1.9 Address

Hosts should use the same subnet mask as the default router, and the two devices should agree as to what subnet exists on their common LAN. Otherwise, problems may exist immediately, as in this example, or they might not exist until other hosts are added later.

Typical Root Causes of DNS Problems

When a host lists the wrong IP addresses for the DNS servers, the symptoms are somewhat obvious: Any user actions that require name resolution fail. Assuming that the only problem is the incorrect DNS setting, any network testing with commands like **ping** and **traceroute** fails when using names, but it works when using IP addresses instead of names.

When a ping of another host's hostname fails, but a ping of that same host's IP address works, some problem exists with DNS. For example, imagine a user calls the help desk complaining that he cannot connect to Server1. The CSR issues a **ping server1** command from the CSR's own PC, which both works and identifies the IP address of Server1 as 1.1.1.1. Then the CSR asks the user to try two commands from the user's PC: both a **ping Server1** command (which fails), and a **ping 1.1.1.1** command (which works). Clearly, the DNS name resolution process on the user's PC is having some sort of problem.

This book does not go into much detail about how DNS truly works behind the scenes, but the following two root causes of DNS problems do fit within the scope of the CCENT and CCNA:

Key Topic

- An incorrect DNS server setting
- An IP connectivity problem between the user's host and the DNS server

Although the first problem may be more obvious, note that it can happen both with static settings on the host and with DHCP. If a host lists the wrong DNS server IP address, and the setting is static, just change the setting. If the wrong DNS server address is learned with DHCP, you need to examine the DHCP server configuration. (If using the IOS DHCP server feature, you make this setting with the **dns-server** *server-address* command in DHCP pool mode.)

The second bullet point brings up an important issue for troubleshooting any real-world networking problem. Most every real user application uses names, not addresses, and most hosts use DNS to resolve names. So, every connection to a new application involves two sets of packets: packets that flow between the host and the DNS server, and packets that flow between the host and the real server, as shown in Figure 5-5.

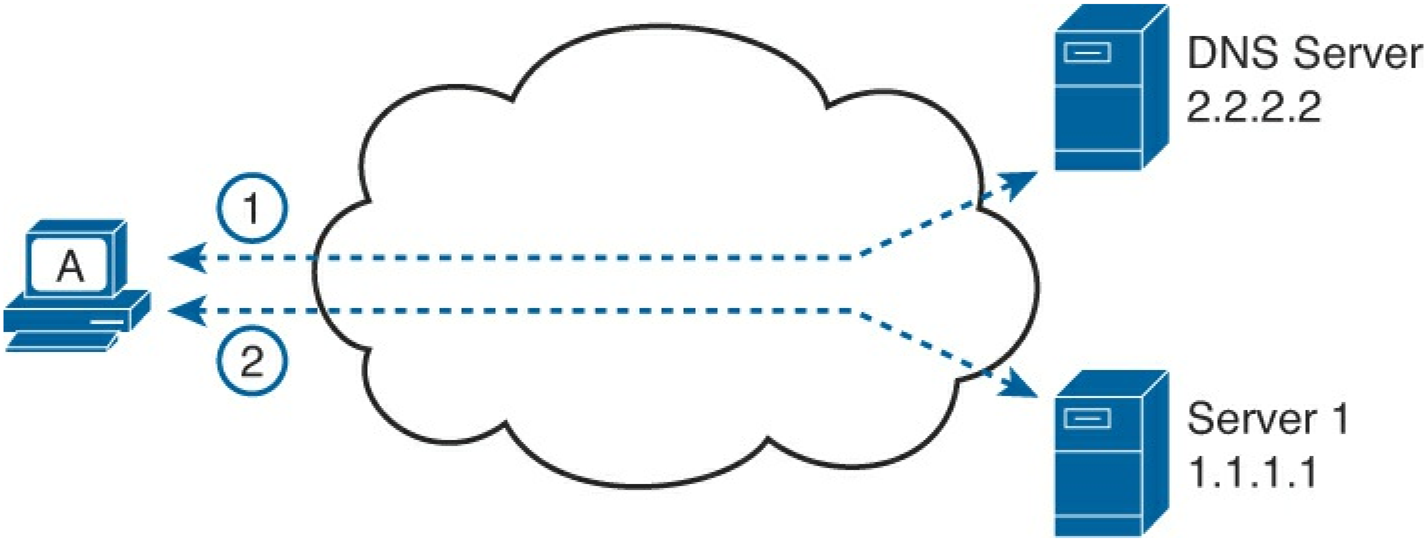


Figure 5-5. DNS Name Resolution Packets Flow First; Then Packets to the Real Server

Finally, before leaving the topic of name resolution, note that the router can be configured with the IP addresses of the DNS servers, so that router commands will attempt to resolve names. For instance, a user of the router command-line interface (CLI) could issue a command **ping server1** and rely on a DNS request to resolve server1 into its matching IP address. To configure a router to use a DNS for name resolution, the router needs the **ip name-server** *dns1-address dns2-address*... global command. It also needs the **ip domain-lookup** global command, which is enabled by default.

For troubleshooting, it can be helpful to set a router or switch DNS settings to match that of the local hosts. However, note that these settings have no impact on the user DNS requests.

> **Note**
>
> On a practical note, IOS defaults with the **ip domain-lookup** command, but with no DNS IP address known. Most network engineers either add the configuration to point to the DNS servers or disable DNS using the **no ip domain-lookup** command.

Wrong Default Router IP Address Setting

Clearly, having a host that lists the wrong IP address as its default router causes problems. Hosts rely on the default router when sending packets to other subnets, and if a host lists the wrong default router setting, the host may not be able to send packets to a different subnet.

Figure 5-6 shows just such an example. In this case, hosts A and B both misconfigure 10.1.3.4 as the default router due to the same piece of bad documentation. Router R3 uses IP address 10.1.3.3. (For the sake of discussion, assume that no other host or router in this subnet currently uses address 10.1.3.4.)

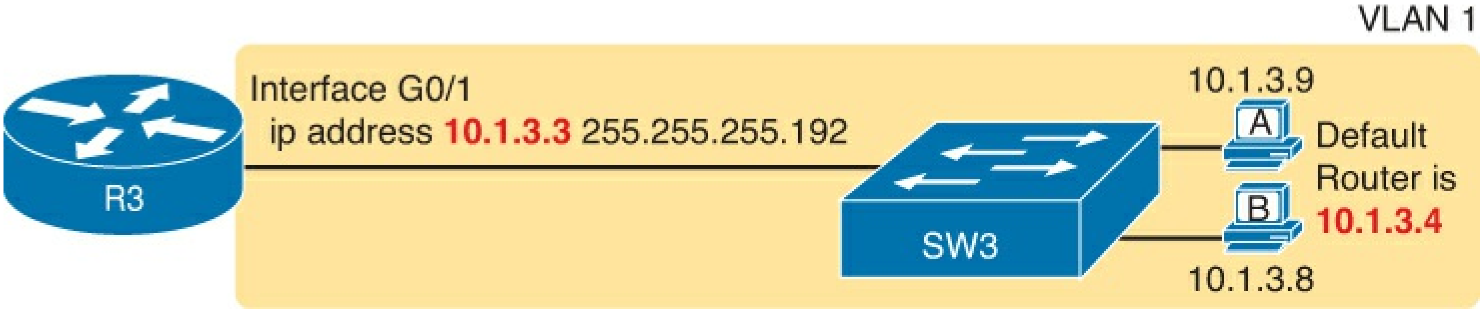


Figure 5-6. Incorrect Default Router Setting on Hosts A and B

In this case, several functions do work. For instance, hosts A and B can send packets to other hosts on the same LAN. The CSR at the router CLI can issue a **ping 10.1.3.9** and **ping 10.1.3.8** command, and both work. As a result of those two working pings, R3 would list the MAC address of the two PCs in the output of the **show arp** command. Similarly, the hosts would list R3's 10.1.3.3 IP address (and matching MAC address) in their ARP caches (usually displayed with the **arp –a** command). The one big problem in this case happens when the hosts try to send packets off-subnet. In that case, try to send the packets to IP address 10.1.3.4 next, which fails.

Root Causes Based on the Default Router's Configuration

While hosts must have correct IPv4 settings to work properly, having correct settings does not guarantee that a LAN-based host can successfully send a packet to the default router. The LAN between the host and the router must work. In addition, the router itself must be working correctly, based on the design of the internetwork.

This next topic looks at problems between hosts and their default router in which the root cause exists on the router. In particular, this topic looks at three main topics. The first topic looks at the trunking configuration required on a router to support multiple VLANs (known as router on a stick, or ROAS). Following that, the text examines typical DHCP issues. The final root cause discussed here is the status of the router interface and what causes that interface to fail.

Mismatched VLAN Trunking Configuration with Router on a Stick

Examples that teach configuration details often focus on one topic at a time. For instance, IPv4 configuration examples may show a host and its default router setting with the IP address configured on the router's LAN interface, as shown earlier in Example 5-1. However, the details of the LAN to which the host and router attach may be completely omitted, to focus on the IPv4 details.

Troubleshooting, both in real life and on the exams, requires that you put all the pieces together. This next example shows a great case of how the troubleshooting process suffers if you forget to think about both the router and switch part of the problem. This example shows a valid router configuration that, unfortunately, does not match the configuration on the neighboring LAN switch like it should.

The next example focuses on how to connect routers to the subnets on multiple VLANs in the same campus LAN. Today, most sites in an enterprise LAN use at least two VLANs. To make routing work today, one of two options is typically used:

- **Router on a Stick (ROAS):** A router connects to the LAN, with one physical interface configured for VLAN trunking. The router has an IP address in each subnet, with one subnet per VLAN. The router configuration adds each matched subnet and associated VLAN to a subinterface.
- **Layer 3 switch:** Also called a multilayer switch, a Layer 3 switch performs the same job as a router using ROAS, but the switch has routing functions built in. The switch configuration adds each matched subnet and associated VLAN to a VLAN interface.

This example happens to use ROAS, but many of the same kinds of mistakes shown here can be made with Layer 3 switch configurations as well.

First, the following list outlines the rules for configuring ROAS, using 802.1Q, on both the router and the neighboring switch:

Key Topic

Step 1. On the router, for each VLAN that is not the native VLAN, do the following:

   A. Create a unique subinterface for each VLAN that needs to be routed (**interface** *type number.subint*).

   B. Enable 802.1Q, and associate one specific VLAN with the subinterface in subinterface config mode (**encapsulation dot1q** *vlan-id*).

   C. Configure IP settings (address and mask) in subinterface config mode (**ip address** *address mask*).

Step 2. On the router, for the native VLAN, if using it, use one of the two following options:

   A. Configure just like for other VLANs, except add the **native** keyword to the encapsulation command (**encapsulation dot1q** *vlan-id* **native**).

   Or

   B. Configure the IP address on the physical LAN interface, without a subinterface and without the **encapsulation dot1q** command.

Step 3. On the switch, enable trunking (because the router will not negotiate to enable 802.1Q trunking):

   A. Enable trunking with the **switchport mode trunk** interface subcommand.

   B. Set the native VLAN to the same VLAN expected on the router, using the **switchport trunk native vlan** *vlan-id* interface subcommand.

Keeping that long list handy for reference, let's next walk through a brief example of the router configuration. First, imagine that previously a site used a single VLAN; so, the router configuration ignored VLAN trunking, with the IP address configured on the physical LAN interface on the router. All hosts sat in default VLAN 1. The router could ignore the VLAN details, not use trunking, and act as default router for all hosts in VLAN 1, as shown in Figure 5-7.

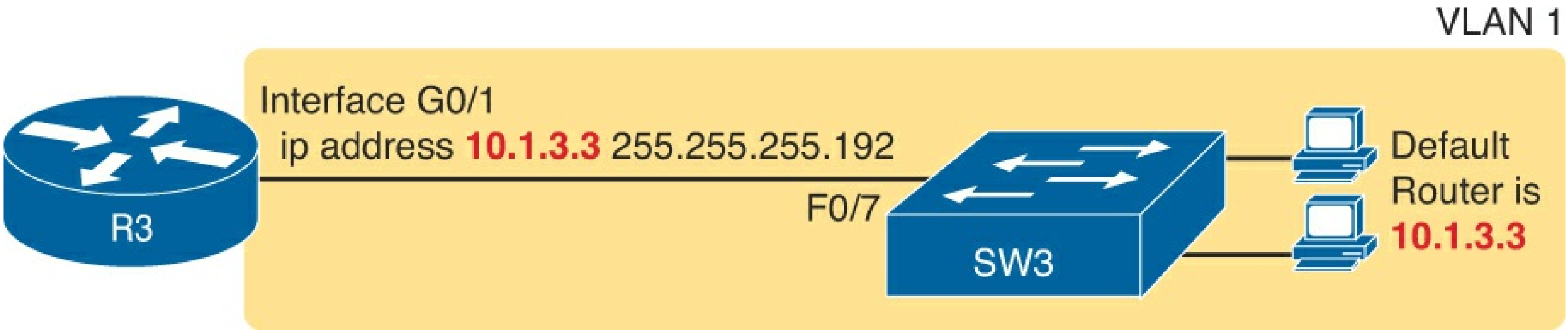


Figure 5-7. Router IP Address Configuration, Without Trunking

Then, management planned an expansion in which a second VLAN will be used. This particular company has one network engineer in charge of routers and the other in charge of switches. When planning the changes with the switch engineer, the two engineers did not listen to each other very well, and then the router engineer went off to plan the changes to the router. The router engineer planned to make the following changes to use ROAS:

- Use ROAS on interface G0/1 to support both users in old subnet 10.1.3.0/26, in VLAN 1, and users in new subnet 10.1.3.64/26, in VLAN 2.
- To support VLAN 1 users, leave 10.1.3.3/26 configured as is on the physical interface. This takes advantage of the option to configure the native VLAN IP address on the physical interface because VLAN 1 is the default native VLAN.

- Add a ROAS subinterface to the router configuration to support VLAN 2, using address 10.1.3.65/26 as the router IP address/mask in that subnet.

Figure 5-8 shows the concepts and configuration.

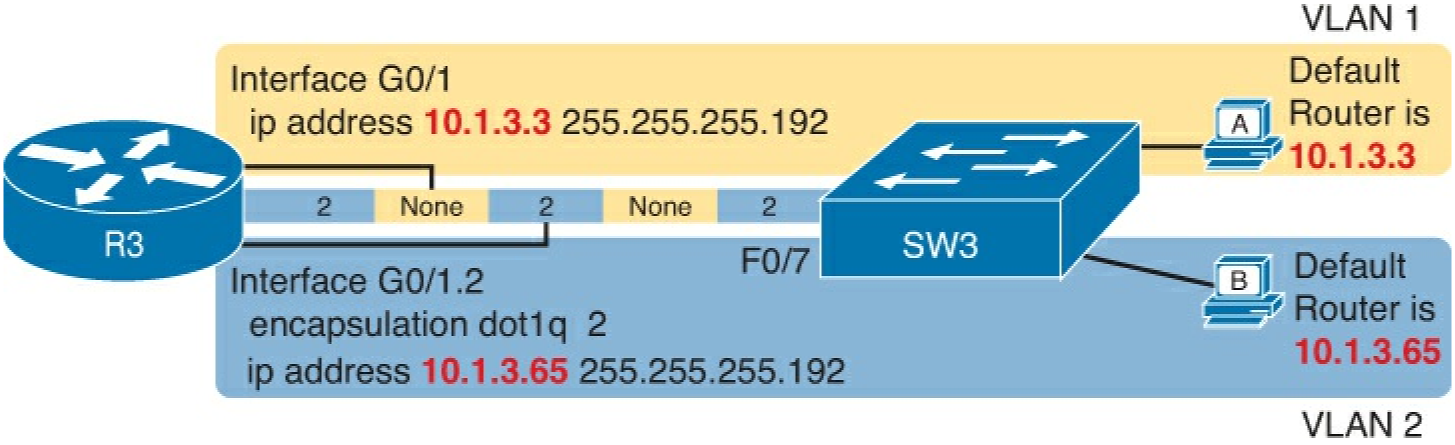

VLAN 1
Interface G0/1
ip address 10.1.3.3 255.255.255.192
Default Router is 10.1.3.3
A
R3
2
None
2
None
2
F0/7
SW3
B
Default Router is 10.1.3.65
Interface G0/1.2
encapsulation dot1q 2
ip address 10.1.3.65 255.255.255.192
VLAN 2

Figure 5-8. Router IP Address Configuration, with ROAS, and Native VLAN 1

This configuration could work perfectly well—as long as the switch has a matching correct VLAN trunking configuration. The router configuration implies a couple of things about VLAN trunking, as follows:

- With the IP address listed on physical interface G0/1, the configuration implies that the router intends to use the native VLAN, sending and receiving untagged frames.
- The router intends to use VLAN 2 as a normal VLAN, sending and receiving frames tagged as VLAN 2.

The switch (SW3) needs to configure VLAN trunking to match that logic. In this case, that means to enable trunking on that link, support VLANs 1 and 2, and make sure VLAN 1 is the native VLAN. Instead, in this case, the switch engineer actually added the trunk configuration to the wrong port, with the F0/7 port, connected to router R3, having these settings:

switchport mode access—The port does not trunk.

switchport access vlan 7—The port is assigned to VLAN 7.

The first command confirms, without a doubt, that the link from R3 to SW3 does not trunk. SW1 will not pass any VLAN 2 traffic over that link at all. A standard ping of host B's IP address from R3 fails; likewise, a **ping 10.1.3.65** command from host B fails.

The second command states that the access VLAN on F0/7 is VLAN 7, which means that SW1 will not forward VLAN 1's traffic over the link to R3, either. Again, pings between R3 and hosts in VLAN 1 will fail as well.

In summary, for ROAS configurations, take the time to verify the matching configuration on the neighboring switch. In particular

Key Topic

- Make sure the switch enables trunking (**switchport mode trunk**).
- Make sure the switch sets the correct VLAN as that trunk's native VLAN (**switchport trunk native vlan** *vlan-id*).
- Make sure the switch knows about all the VLANs the router has configured (**vlan** *vlan-id*).

DHCP Relay Issues

Hosts that use DHCP to lease an IP address (and learn other settings) rely on the network to pass the DHCP messages. In particular, if the internetwork uses a centralized DHCP server, with many remote LAN subnets using the DHCP server, the routers have to enable a feature called *DHCP Relay* to make DHCP work. Without DHCP Relay, DHCP requests from hosts never leave the local LAN subnet.

Figure 5-9 shows the big ideas behind how DHCP Relay works. In this example, a DHCP client (Host A) sits on the left, with the DHCP server (172.16.2.11) on the right. The client begins the DHCP lease process by sending a DHCP Discover message, one that would flow only across the local LAN without DHCP Relay configured on router R1. To be ready to forward the Discover message, R1 enables DHCP Relay with the **ip helper-address 172.16.2.11** command configured under its G0/0 interface.

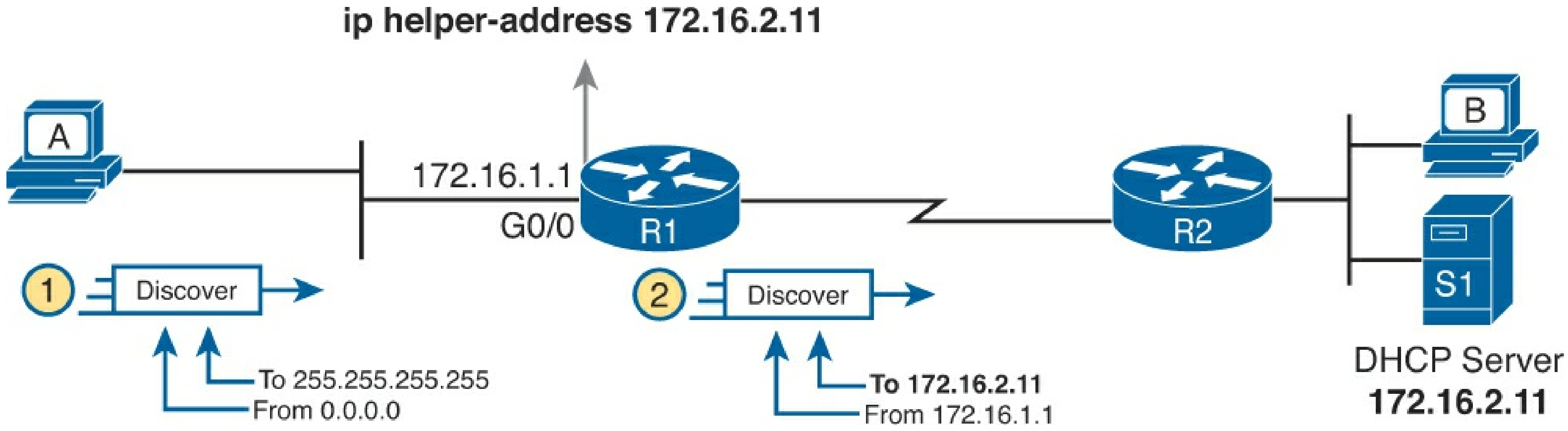


Figure 5-9. IP Helper Address Effect

The steps in the figure point out the need for DHCP Relay. At Step 1, host A sends a message, with destination IP and L2 broadcast address of 255.255.255.255 and ff:ff:ff:ff:ff.ff, respectively. Packets sent to this IP address, the "local subnet broadcast address," should never be forwarded past the router. All devices on the subnet receive and process the frame. Additionally, because the **ip helper-address** command configured on R1, router R1 will continue to deencapsulate the frame and packet to identify that it is a DHCP request and take action. Step 2 shows the results of DHCP Relay, where R1 changes both the source and destination IP address, with R1 routing the packet to the address listed in the command: 172.16.2.11.

Now, back to troubleshooting. Messages sent by a DHCP client can reach the DHCP server if the following are true:

Key Topic

- The server is in the same subnet as the client, with connectivity working between the two.
- The server is on another subnet, with the router on the same subnet as the client correctly implementing DHCP Relay, and with IP connectivity from that router to the DHCP server.

Two common mistakes can be made with DHCP Relay, both of which are fairly obvious. If the router omits the **ip helper-address** command on a LAN interface (or subinterface when using ROAS, or VLAN interface with a multilayer switching [MLS] configuration), DHCP fails for those clients. If the configuration includes the **ip helper-address** command but lists the wrong DHCP server IP address, again DHCP fails completely.

The symptom in both cases is that the client learns nothing with DHCP.

For instance, Example 5-2 shows an updated configuration for ROAS on router R3, based on the same scenario as in Figure 5-8. The router configuration works fine for supporting IPv4 and making the router reachable. However, only one subinterface happens to list an **ip helper-address** command.

Example 5-2. Forgetting to Support DHCP Relay on a ROAS Subinterface

Click here to view code image

```
interface GigabitEthernet0/1
ip address 10.1.3.3 255.255.255.192
ip helper-address 10.1.2.130
!
interface GigabitEthernet0/1.2
encapsulation dot1q 2
ip address 10.1.3.65 255.255.255.192
```

In this case, hosts in VLAN 1 that want to use DHCP can, assuming the host at address 10.1.2.130 is indeed the DHCP server. However, hosts in VLAN 2 will fail to learn settings with DHCP because of the lack of an **ip helper-address** command.

Router LAN Interface and LAN Issues

At some point, the problem isolation process may show that a host cannot ping its default router and vice versa. That is, neither device can send an IP packet to the other device on the same subnet. This basic test tells the engineer that the router, host, and LAN between them, for whatever reasons, cannot pass the packet encapsulated in an Ethernet frame between the two devices.

The root causes for this basic LAN connectivity issue fall into two categories:

- Problems that cause the router LAN interface to fail
- Problems with the LAN itself

A router's LAN interface must be in a working state before the router will attempt to send packets out that interface (or receive packets in that interface). Specifically, the router LAN interface must be in an up/up state; if in any other state, the router will not use the interface for packet forwarding. So, if a ping from the router to a LAN host fails (or vice versa), check the interface status, and if not up, find the root cause for the router interface to not be up.

Alternatively, the router interface can be in an up/up state, but problems can exist in the LAN itself. In this case, every topic related to Ethernet LANs may be a root cause. In particular, all the topics reviewed in Chapter 3, such as Ethernet cable pinouts, port security, and even Spanning Tree Protocol, may be root causes of LAN issues.

For instance, in Figure 5-10, router R3 connects to a LAN with four switches. R3's LAN interface (G0/1) can reach an up/up state if the link from R3 to SW1 works. However, many other problems could prevent R3 from successfully sending an IP packet, encapsulated in an Ethernet frame, to the hosts attached to switches SW3 and SW4.

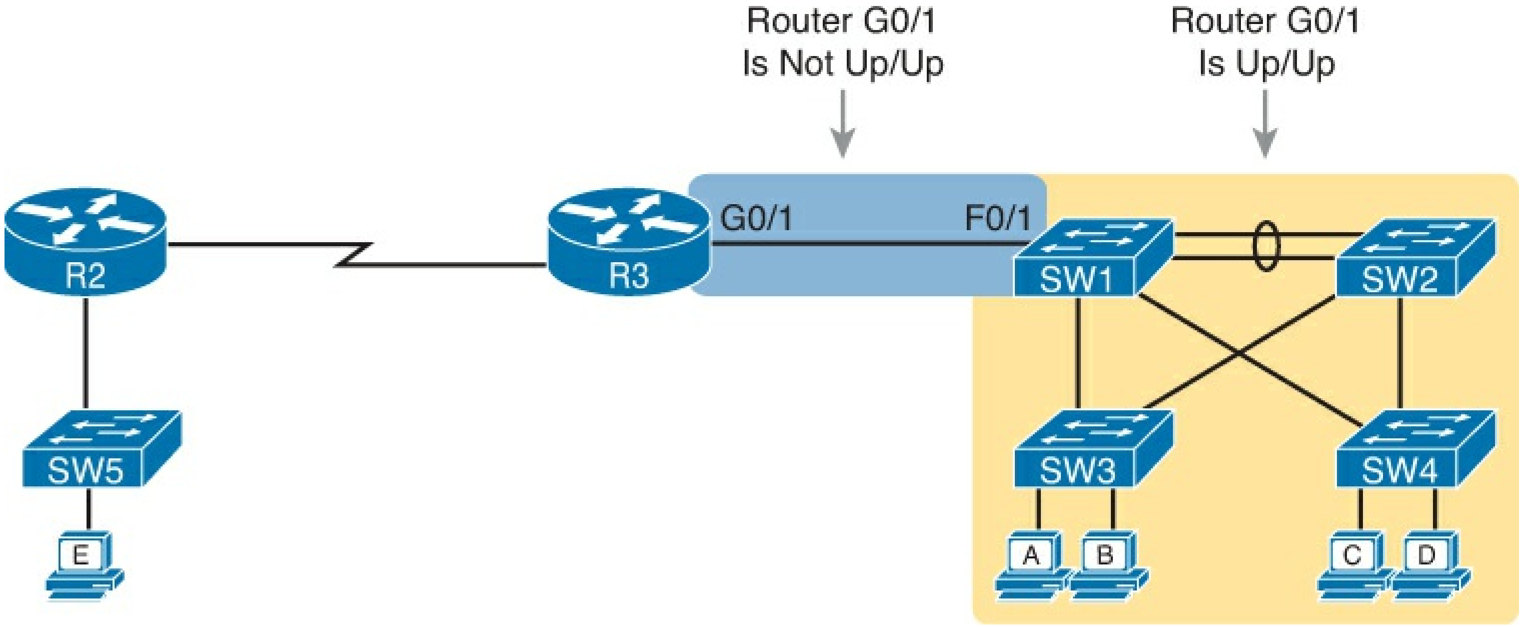


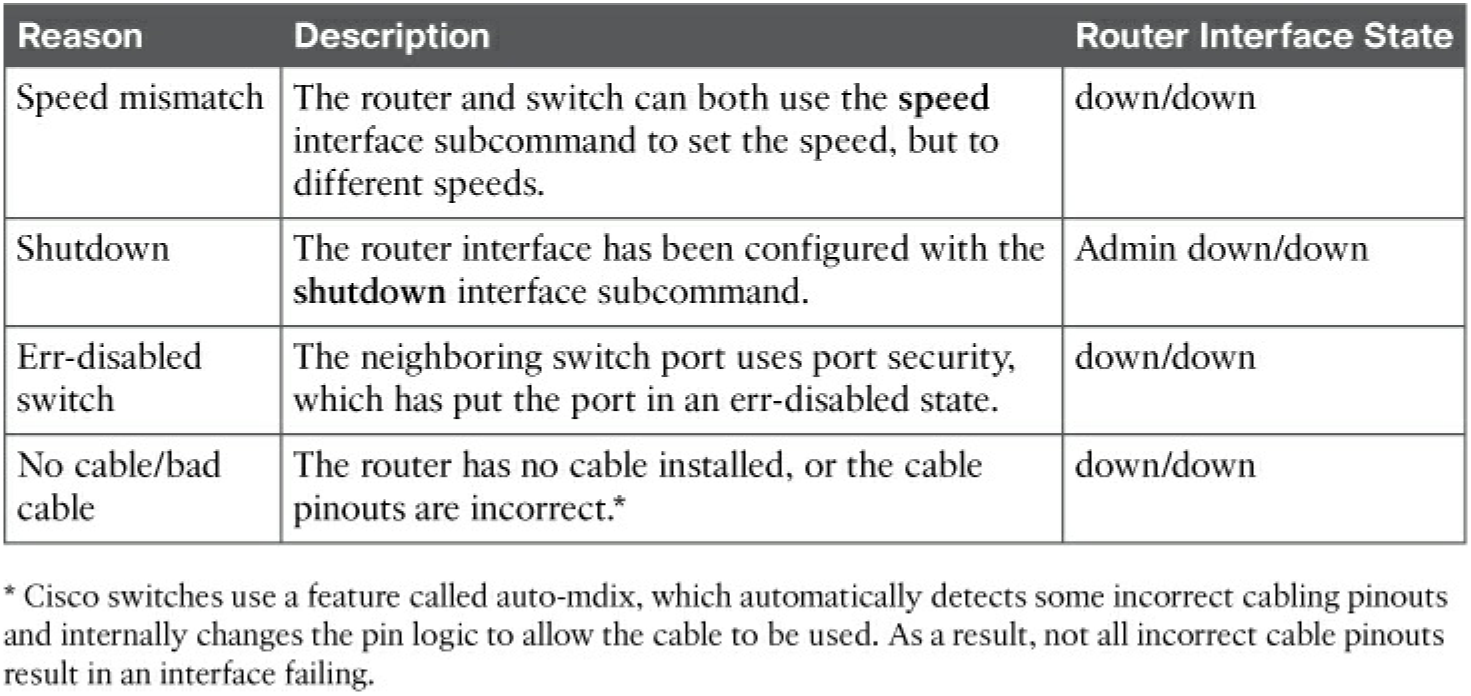
Figure 5-10. Where to Look for Problems Based on Router LAN Interface Status

> **Note**
>
> This book leaves the discussion of LAN issues, as shown on the right side of Figure 5-10, to Part I of this book.

Router LAN interfaces can fail to reach a working up/up state for several reasons. Table 5-1 lists the common reasons discussed within the scope of the CCNA exam.

Key Topic

Table 5-1. Common Reasons Why Router LAN Interfaces Are Not Up/Up



Reason	Description	Router Interface State
Speed mismatch	The router and switch can both use the **speed** interface subcommand to set the speed, but to different speeds.	down/down
Shutdown	The router interface has been configured with the **shutdown** interface subcommand.	Admin down/down
Err-disabled switch	The neighboring switch port uses port security, which has put the port in an err-disabled state.	down/down
No cable/bad cable	The router has no cable installed, or the cable pinouts are incorrect.*	down/down

* Cisco switches use a feature called auto-mdix, which automatically detects some incorrect cabling pinouts and internally changes the pin logic to allow the cable to be used. As a result, not all incorrect cable pinouts result in an interface failing.

Using the speed mismatch root cause as an example, you could configure Figure 5-10's R3's G0/1 with the **speed 1000** command and SW1's F0/1 interface with the **speed 100** command. The link simply cannot work at these different speeds, so the router and switch interfaces both fall to a down/down state. Example 5-3 shows the resulting state, this time with the **show interfaces description** command, which lists one line of output per interface.

Example 5-3. show interfaces description **Command with Speed Mismatch**

Click here to view code image

```
R3# show interfaces description
Interface Status Protocol Description
Gi0/0 up up
Gi0/1 down down link to campus LAN
Se0/0/0 admin down down
Se0/0/1 up up
Se0/1/0 up up
Se0/1/1 admin down down
```

Problems with Routing Packets Between Routers

The first half of this chapter focused on the first hop that an IPv4 packet takes when passing over a network. This second major section now looks at issues related to how routers forward the packet from the default router to the final host.

In particular, this section begins by looking at the IP routing logic inside a single router. These topics review how to understand what a router currently does. Following that, the discussion expands to look at some common root causes of routing problems, causes that come from incorrect IP addressing, particularly when the addressing design uses variable-length subnet masks (VLSM).

The end of this section turns away from the core IP forwarding logic, looking at other issues that impact packet forwarding, including issues related to router interface status (which needs to be up/up) and how IPv4 access control lists (ACL) can filter IPv4 traffic.

IP Forwarding by Matching the Most Specific Route

Any router's IP routing process requires that the router compare the destination IP address of each packet with the existing contents of that router's IP routing table. Often, only one route matches a particular destination address. However, in some cases, a particular destination address matches more than one of the router's routes.

The following CCENT and CCNA features can create overlapping subnets:

- Autosummary (as discussed in Chapter 10, "Implementing EIGRP for IPv4")
- Manual route summarization
- Static routes
- Incorrectly designed subnetting plans that cause subnets overlap their address ranges

In some cases, overlapping routes cause a problem; in other cases, the overlapping routes are just a normal result of using some feature. This section focuses on how a router chooses which of the overlapping routes to use, for now ignoring whether the overlapping routes are a problem. The section "Routing Problems Caused by Incorrect Addressing Plans," later in this chapter, discusses some of the problem cases.

Now on to how a router matches the routing table, even with overlapping routes in its routing table. If only one route matches a given packet, the router uses that one route. However, when more than one route matches a packet's destination address, the router uses the "best" route, defined as follows:

Key Topic

> When a particular destination IP address matches more than one route in a router's IPv4 routing table, the router uses the most specific route—in other words, the route with the longest prefix length mask.

Using show ip route and Subnet Math to Find the Best Route

We humans have a couple of ways to figure out what choice a router makes for choosing the best route. One way uses the **show ip route** command, plus some subnetting math, to decide the route the router will choose. To let you see how to use this option, Example 5-4 shows a series of overlapping routes.

Example 5-4. show ip route **Command with Overlapping Routes**

Click here to view code image

```
R1# show ip route ospf
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
```

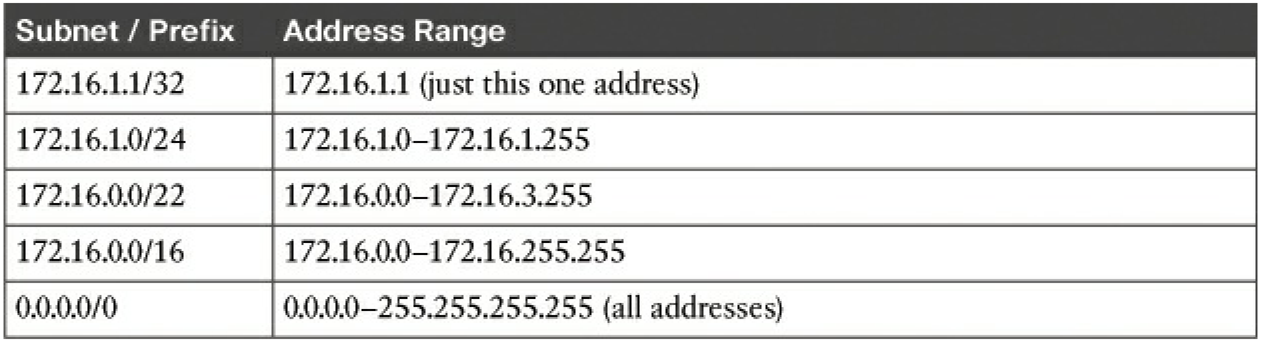
```
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
E1 - OSPF external type 1, E2 - OSPF external type 2
i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
ia - IS-IS inter area, * - candidate default, U - per-user static route
o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
+ - replicated route, % - next hop override

Gateway of last resort is 172.16.25.129 to network 0.0.0.0

172.16.0.0/16 is variably subnetted, 9 subnets, 5 masks
O 172.16.1.1/32 [110/50] via 172.16.25.2, 00:00:04, Serial0/1/1
O 172.16.1.0/24 [110/100] via 172.16.25.129, 00:00:09, Serial0/1/0
O 172.16.0.0/22 [110/65] via 172.16.25.2, 00:00:04, Serial0/1/1
O 172.16.0.0/16 [110/65] via 172.16.25.129, 00:00:09, Serial0/1/0
O 0.0.0.0/0 [110/129] via 172.16.25.129, 00:00:09, Serial0/1/0
!
```

Note

As an aside, the **show ip route ospf** command lists only OSPF-learned routes, but the statistics for numbers of subnets and masks (9 and 5 in the example, respectively) are for all routes, not just OSPF-learned routes.

To predict which of its routes a router will match, two pieces of information are required: the destination IP address of the packet and the contents of the router's routing table. The subnet ID and mask listed for a route defines the range of addresses matched by that route. With a little subnetting math, a network engineer can find the range of addresses matched by each route. For instance, Table 5-2 lists the five subnets listed in Example 5-4 and the address ranges implied by each.

Table 5-2. Analysis of Address Ranges for the Subnets in Example 5-4



Subnet / Prefix	Address Range
172.16.1.1/32	172.16.1.1 (just this one address)
172.16.1.0/24	172.16.1.0–172.16.1.255
172.16.0.0/22	172.16.0.0–172.16.3.255
172.16.0.0/16	172.16.0.0–172.16.255.255
0.0.0.0/0	0.0.0.0–255.255.255.255 (all addresses)

Note

The route listed as 0.0.0.0/0 is the default route.

As you can see from these ranges, several of the routes' address ranges overlap. When matching more than one route, the route with the longer prefix length is used. That is, a route with *16 is better than a route with* 10; a route with a *25 prefix is better than a route with a* 20 prefix; and so on.

For example, a packet sent to 172.16.1.1 actually matches all five routes listed in the routing table in Example 5-4. The various prefix lengths range from *0 to* 32. The longest prefix (largest *P value, meaning the best and most specific route) is* 32. So, a packet sent to 172.16.1.1 uses the route to 172.16.1.1/32, and not the other routes.

The following list gives some examples of destination IP addresses. For each address, the list describes the routes from Table 5-2 that the router would match, and which specific route the router would use.

- **172.16.1.1:** Matches all five routes; the longest prefix is *32, the route to 172.16.1.1*32.
- **172.16.1.2:** Matches last four routes; the longest prefix is *24, the route to 172.16.1.0*24.
- **172.16.2.3:** Matches last three routes; the longest prefix is *22, the route to 172.16.0.0*22.
- **172.16.4.3:** Matches the last two routes; the longest prefix is *16, the route to 172.16.0.0*16.

Using show ip route ***address*** to Find the Best Route

A second way to identify the route a router will use, one that does not require any subnetting math, is the **show ip route** *address* command. The last parameter on this command is the IP address of an assumed IP packet. The router replies by listing the route it would use to route a packet sent to that address.

For example, Example 5-5 lists the output of the **show ip route 172.16.4.3** command on the same router used in Example 5-4. The first line of (highlighted) output lists the matched route: the route to 172.16.0.0/16. The rest of the output lists the details of that particular route, like the outgoing interface of S0/1/0 and the next-hop router of 172.16.25.129.

Example 5-5. show ip route **Command with Overlapping Routes**

Click here to view code image

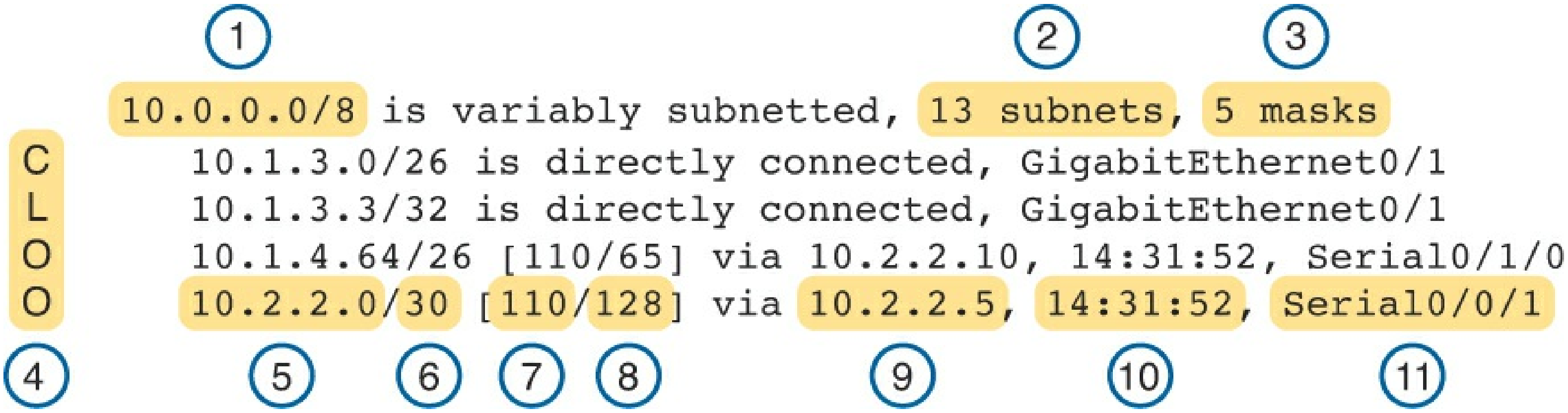
```
R1# show ip route 172.16.4.3
Routing entry for 172.16.0.0/16
Known via "ospf 1", distance 110, metric 65, type intra area
Last update from 10.2.2.5 on Serial0/1/0, 14:22:06 ago
Routing Descriptor Blocks:
* 172.16.25.129, from 172.16.25.129, 14:22:05 ago, via Serial0/1/0
Route metric is 65, traffic share count is 1
```

Certainly, if you have an option, just using a command to check what the router actually chooses is a much quicker option than doing the subnetting math.

show ip route **Reference**

The **show ip route** command plays a huge role in troubleshooting IP routing and IP routing protocol problems. Many chapters in this book and in the ICND1 book mention various facts about this command. This section pulls the concepts together in one place for easier reference and study.

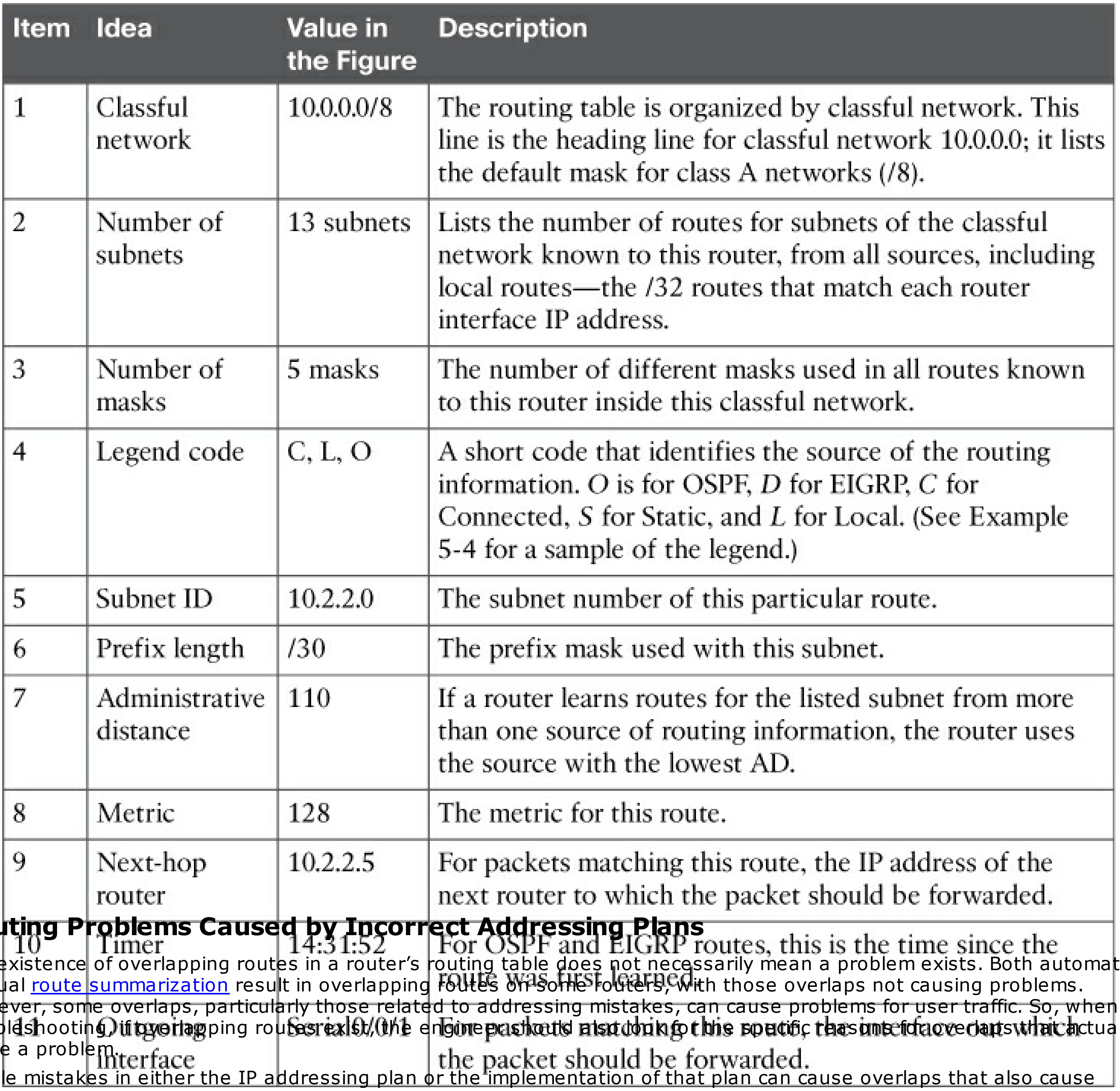
Figure 5-11 shows the output of a sample **show ip route** command. The figure numbers various parts of the command output for easier reference, with Table 5-3 describing the output noted by each number.



```
   10.0.0.0/8 is variably subnetted, 13 subnets, 5 masks
C     10.1.3.0/26 is directly connected, GigabitEthernet0/1
L     10.1.3.3/32 is directly connected, GigabitEthernet0/1
O     10.1.4.64/26 [110/65] via 10.2.2.10, 14:31:52, Serial0/1/0
O     10.2.2.0/30 [110/128] via 10.2.2.5, 14:31:52, Serial0/0/1
```

Figure 5-11. show ip route **Command Output Reference**

Table 5-3. Descriptions of the show ip route **Command Output**



Item	Idea	Value in the Figure	Description
1	Classful network	10.0.0.0/8	The routing table is organized by classful network. This line is the heading line for classful network 10.0.0.0; it lists the default mask for class A networks (/8).
2	Number of subnets	13 subnets	Lists the number of routes for subnets of the classful network known to this router, from all sources, including local routes—the /32 routes that match each router interface IP address.
3	Number of masks	5 masks	The number of different masks used in all routes known to this router inside this classful network.
4	Legend code	C, L, O	A short code that identifies the source of the routing information. *O* is for OSPF, *D* for EIGRP, *C* for Connected, *S* for Static, and *L* for Local. (See Example 5-4 for a sample of the legend.)
5	Subnet ID	10.2.2.0	The subnet number of this particular route.
6	Prefix length	/30	The prefix mask used with this subnet.
7	Administrative distance	110	If a router learns routes for the listed subnet from more than one source of routing information, the router uses the source with the lowest AD.
8	Metric	128	The metric for this route.
9	Next-hop router	10.2.2.5	For packets matching this route, the IP address of the next router to which the packet should be forwarded.
10	Timer	14:31:52	For OSPF and EIGRP routes, this is the time since the route was first learned.
11	Outgoing interface	Serial0/0/1	For packets matching this route, the interface out which the packet should be forwarded.

Routing Problems Caused by Incorrect Addressing Plans

The existence of overlapping routes in a router's routing table does not necessarily mean a problem exists. Both automatic and manual route summarization result in overlapping routes on some routers, with those overlaps not causing problems. However, some overlaps, particularly those related to addressing mistakes, can cause problems for user traffic. So, when troubleshooting, if overlapping routes exist, the engineer should also look for the specific reasons for overlaps that actually cause a problem.

Simple mistakes in either the IP addressing plan or the implementation of that plan can cause overlaps that also cause problems. In these cases, one router claims to be connected to a subnet with one address range, while another router claims to be connected to another subnet with an overlapping range, breaking IP addressing rules. The symptoms are that the routers sometimes forward the packets to the right host, but sometimes not.

This problem can occur whether or not VLSM is used. However, the problem is much harder to find when VLSM is used. This section reviews VLSM, shows examples of the problem both with and without VLSM, and discusses the configuration and verification commands related to these problems.

Recognizing When VLSM Is Used or Not

An internetwork is considered to be using VLSM when multiple subnet masks are used for different subnets of *a single classful network*. For example, if in one internetwork all subnets come from network 10.0.0.0, and masks *24,* 26, and /30 are used, the internetwork uses VLSM.

Sometimes people fall into the trap of thinking that any internetwork that uses more than one mask must be using VLSM, but that is not always the case. For instance, if an internetwork uses subnets of network 10.0.0.0, all of which use mask 255.255.240.0, and subnets of network 172.16.0.0, all of which use a 255.255.255.0 mask, the design does not use VLSM. Two different masks are used, but only one mask is used in any single classful network. The design must use more than one mask for subnets of a single classful network to be using VLSM.

Only classless routing protocols can support VLSM. The current CCENT and CCNA Routing and Switching certifications cover only classless routing protocols (OSPF and EIGRP), so in all routing protocol discussions for this book, VLSM should be supported. However, for real life, note that RIPv2 (as a classless routing protocol) also supports VLSM, whereas classful routing protocols RIPv1 and Interior Gateway Routing Protocol (IGRP) cannot.

Overlaps When Not Using VLSM

Even when you are not using VLSM, addressing mistakes that create overlapping subnets can occur. For instance, Figure 5-12 shows a sample network with router LAN IP address/mask information. An overlap exists, but it might not be obvious at first glance.

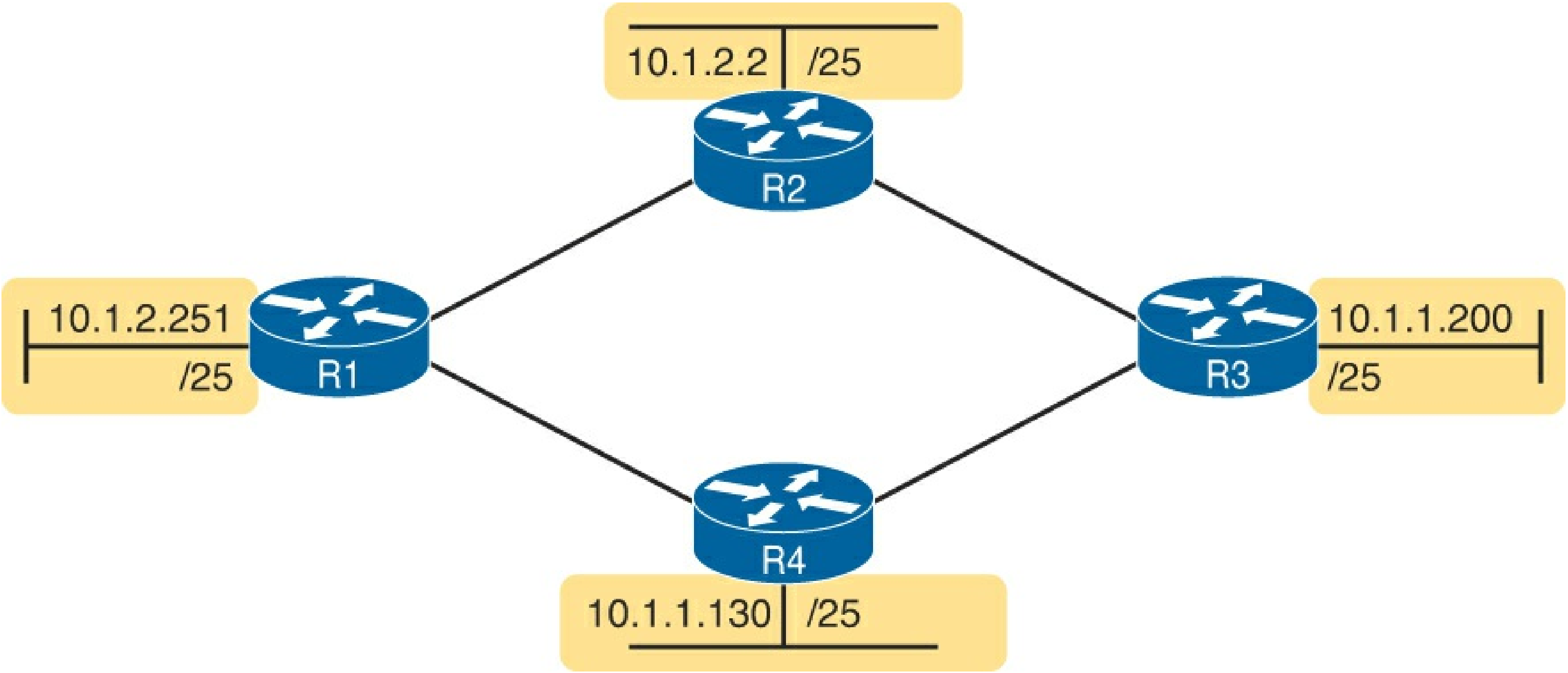

10.1.2.2
/25
R2
10.1.2.251
/25
R1
10.1.1.200
/25
R3
R4
10.1.1.130
/25

Figure 5-12. IP Addresses on LAN Interfaces, with One Mask (/25) in Network 10.0.0.0

If an overlap exists when all subnets use the same mask, the overlapping subnets have the exact same subnet ID, and the exact same range of IP addresses in the subnet. To find the overlap, all you have to do is calculate the subnet ID of each subnet and compare the numbers. For instance, Figure 5-13 shows an updated version of Figure 5-12, with subnet IDs shown and with identical subnet IDs for the LANs off R3 and R4.

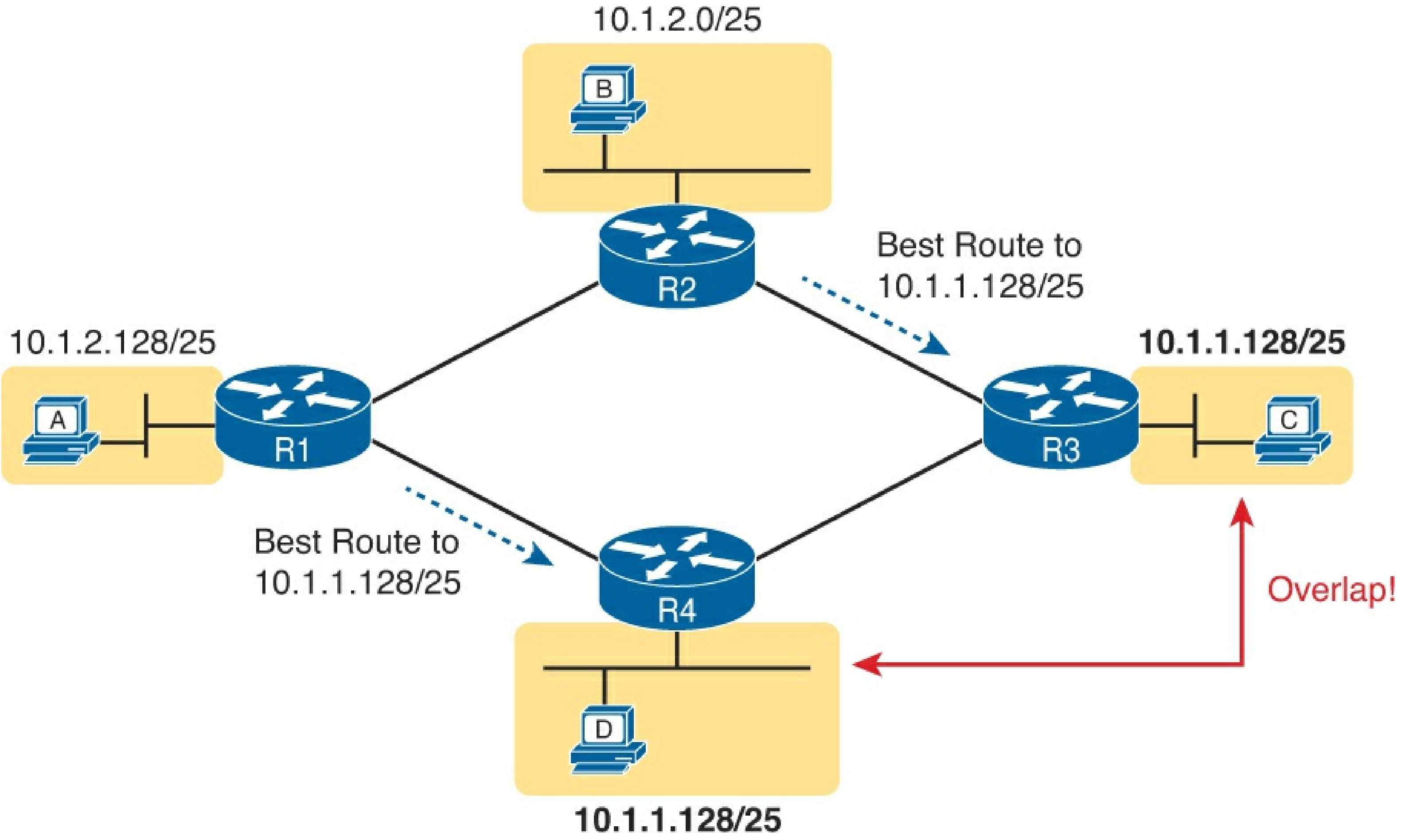

10.1.2.0/25
B
R2
Best Route to
10.1.1.128/25
10.1.2.128/25
A
R1
10.1.1.128/25
C
R3
Best Route to
10.1.1.128/25
R4
Overlap!
D
10.1.1.128/25

Figure 5-13. Subnet IDs Calculated from Figure 5-12

Using the same subnet in two different places (as is done in Figure 5-13) breaks the rules of IPv4 addressing because the routers get confused about where to send packets. In this case, for packets sent to subnet 10.1.1.128/25, some routers send packets so they arrive at R3, whereas others think the best route points toward R4. Assuming all routers use a routing protocol, such as OSPF, both R3 and R4 advertise a route for 10.1.1.128/25.

In this case, R1 and R2 will likely send packets to two different instances of subnet 10.1.1.128/25. With these routes, hosts near R1 will be able to communicate with 10.1.1.128/25 hosts off R4's LAN, but not those off R3's LAN, and vice versa.

Finally, although the symptoms point to some kind of routing issues, the root cause is an invalid IP addressing plan. No IP addressing plan should use the same subnet on two different LANs, as was done in this case. The solution: Change R3 or R4 to use a different, nonoverlapping subnet on its LAN interface.

Overlaps When Using VLSM

When using VLSM, the same kinds of addressing mistakes can lead to overlapping subnets; they just may be more difficult to notice.

First, overlaps between subnets that have different masks will cause only a partial overlap. That is, two overlapping subnets will have different sizes and possibly different subnet IDs. The overlap occurs between all the addresses of the smaller subnet, but with only part of the larger subnet. Second, the problems between hosts only occur for some destinations (specifically the subset of addresses in the overlapped ranges), making it even tougher to characterize the problem.

For instance, Figure 5-14 shows an example with a VLSM overlap. The figure shows only the IP address/mask pairs of router and host interfaces. First, look at the example and try to find the overlap by looking at the IP addresses.

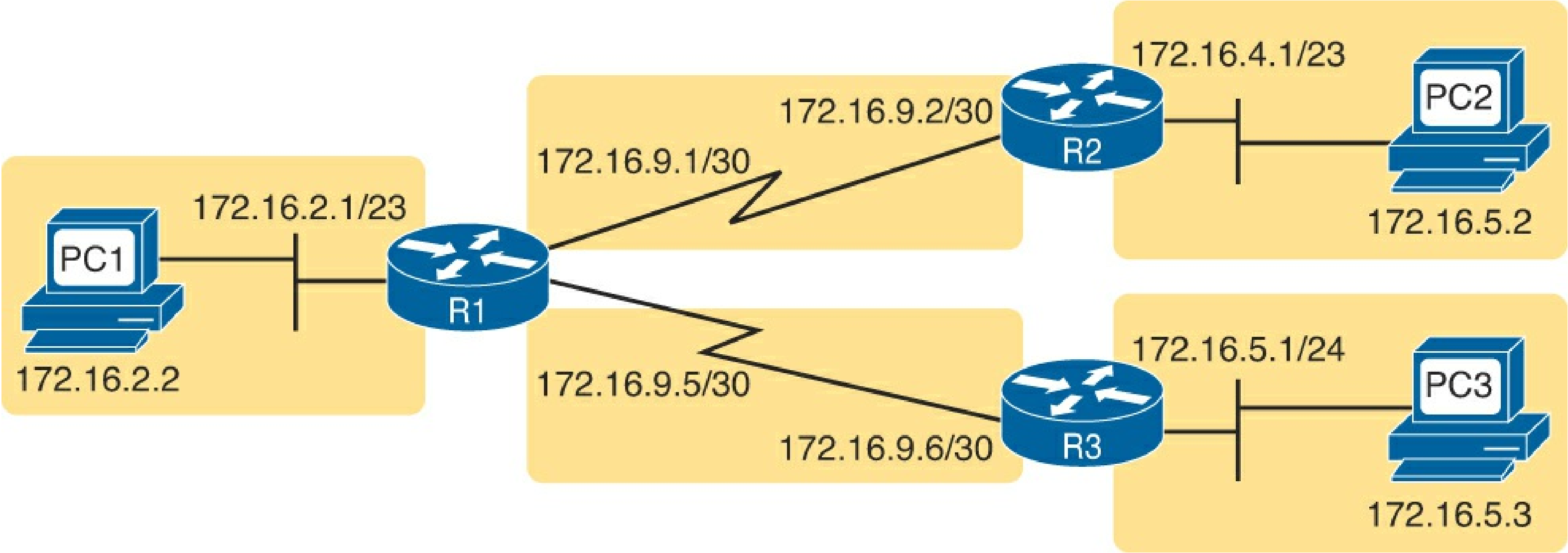


Figure 5-14. VLSM IP Addressing Plan in Network 172.16.0.0

To find the overlap, the person troubleshooting the problem needs to analyze each subnet, finding not only the subnet ID but also the subnet broadcast address and the range of addresses in the subnet. If the analysis stops with just looking at the subnet ID, the overlap may not be noticed (as is the case in this example).

Figure 5-15 shows the beginning analysis of each subnet, with only the subnet ID listed. Note that the two overlapping subnets have different subnet IDs, but the lower-right subnet (172.16.5.0/24) completely overlaps with part of the upper-right subnet (172.16.4.0/23). (Subnet 172.16.4.0/23 has a subnet broadcast address of 172.16.5.255, and subnet 172.16.5.0/24 has a subnet broadcast address of 172.16.5.255.)

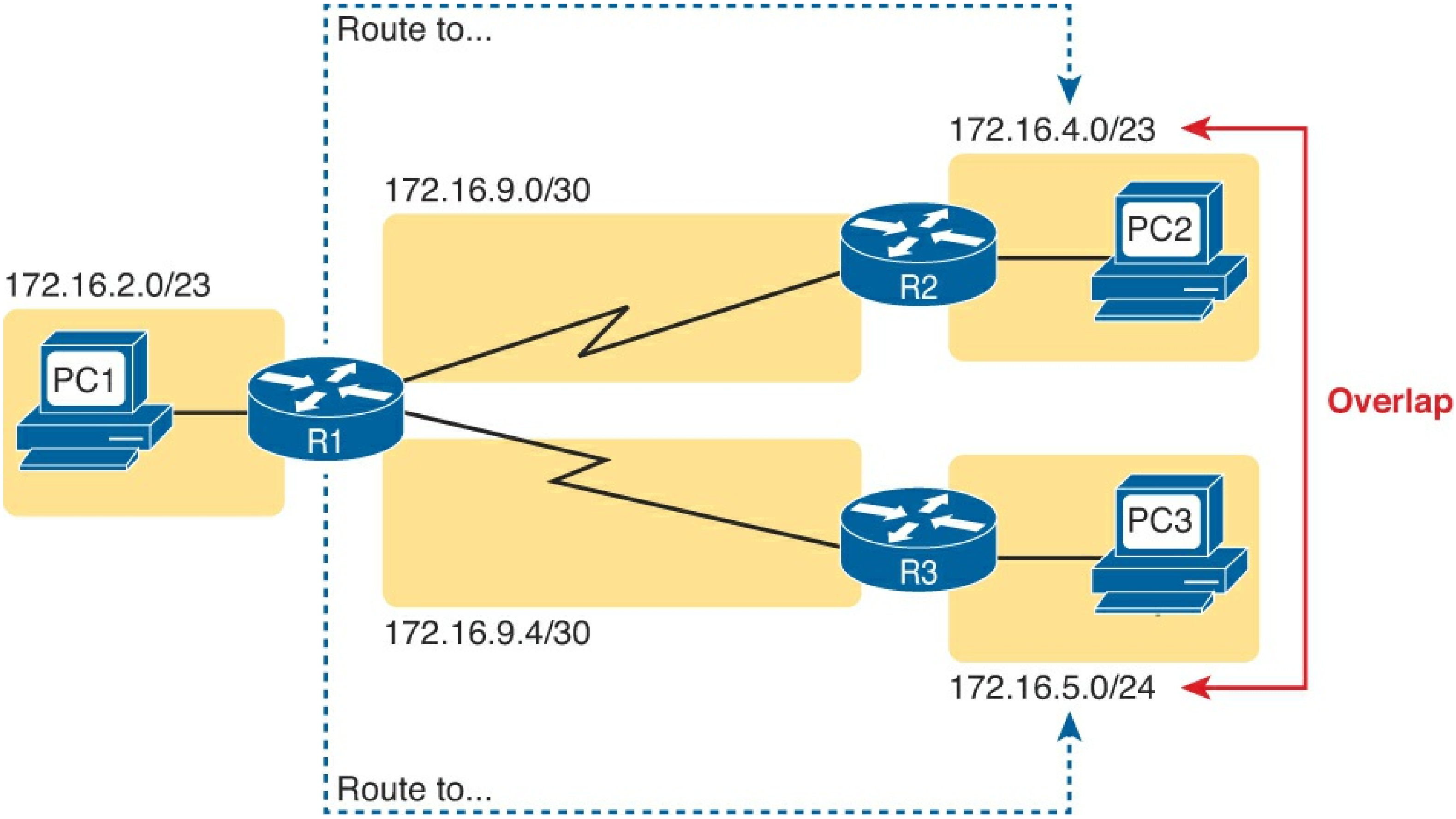


Figure 5-15. A VLSM Overlap Example, But with Different Subnet IDs

To be clear, the design with actual subnets whose address ranges overlap is incorrect and should be changed. However, once implemented, the symptoms show up as routing problems, like the similar case without VLSM. **ping** commands fail, and **traceroute** commands do complete for only certain hosts (but not all).

Configuring Overlapping VLSM Subnets

IP subnetting rules require that the address ranges in the subnets used in an internetwork should not overlap. IOS sometimes can recognize when a new **ip address** command creates an overlapping subnet, but sometimes not, as follows:

Key Topic

- **Preventing the overlap on a single router:** IOS detects the overlap when the **ip address** command implies an overlap with another **ip address** command *on the same router*.
- **Allowing the overlap on different routers:** IOS cannot detect an overlap when an **ip address** command overlaps with an **ip address** command on another router.

The router shown in Example 5-6 prevents the configuration of an overlapping VLSM subnet. The example shows router R3 configuring Fa0/0 with IP address 172.16.5.1/24 and attempting to configure Fa0/1 with 172.16.5.193/26. The ranges of addresses in each subnet are as follows:

Subnet 172.16.5.0/24: 172.16.5.1 – 172.16.5.254

Subnet 172.16.5.192/26: 172.16.5.193 – 172.16.5.254

Example 5-6. Single Router Rejects Overlapped Subnets

Click here to view code image

```
R3# configure terminal
R3(config)# interface Fa0/0
R3(config-if)# ip address 172.16.5.1 255.255.255.0
R3(config-if)# interface Fa0/1
R3(config-if)# ip address 172.16.5.193 255.255.255.192
% 172.16.5.192 overlaps with FastEthernet0/0
R3(config-if)#
```

IOS knows that it is illegal to overlap the ranges of addresses implied by a subnet. In this case, because both subnets would be connected subnets, this single router knows that these two subnets should not coexist because that would break subnetting rules, so IOS rejects the second command.

As an aside of how IOS handles these errors, IOS only performs the subnet overlap check for interfaces that are not in a shutdown state. When configuring an interface in shutdown state, IOS actually accepts the **ip address** command that would cause the overlap. Later, when the **no shutdown** command is issued, IOS checks for the subnet overlap and issues the same error message shown in Example 5-6. IOS leaves the interface in the shutdown state until the overlap condition has been resolved.

IOS cannot detect the configuration of overlapping subnets on different routers, as shown in Example 5-7. The example shows the configuration of the two overlapping subnets on R2 and R3 from Figure 5-15.

Example 5-7. Two Routers Accept Overlapped Subnets

Click here to view code image

```
! First, on router R2
R2# configure terminal
R2(config)# interface G0/0
R2(config-if)# ip address 172.16.4.1 255.255.254.0
```

```
! Next, on router R3
R3# configure terminal
R3(config)# interface G0/0
R3(config-if)# ip address 172.16.5.1 255.255.255.0
```

Router WAN Interface Status

One of the steps in the IP routing troubleshooting process described earlier, in the “Router LAN Interface and LAN Issues” section, says to check the interface status, ensuring that the required interface is working. For a router interface to be working, the two interface status codes must both be listed as up, with engineers usually saying the interface is “up and up.”

So far, the ICND1 and ICND2 books have explored only basic information about how serial links work. For now, know that both routers must have working serial interfaces in an up/up state before they can send IPv4 packets to each other. The two routers should also have serial IP addresses in the same subnet.

Later, the chapters in Part IV further develop the details of WAN links, including what is required for routers to use these links to forward IP packets.

Filtering Packets with Access Lists

Access control lists (ACL) cause some of the biggest challenges when troubleshooting problems in real networking jobs. End-user packets sent by user applications do not look exactly like packets sent by testing tools such as ping and traceroute. The ACLs sometimes filter the ping and traceroute traffic, making the network engineer think some other kind of problems exists when no problems exist at all. Or, the problem with the end-user traffic really is caused by the ACL, but the ping and traceroute traffic works fine, because the ACL filters the user traffic but not the ping and traceroute traffic.

This section summarizes some tips for attacking ACL-related problems in real life and on the exams:

Step 1. Determine on which interfaces ACLs are enabled, and in which direction (**show running-config, show ip interfaces**).

Step 2. Determine which ACL statements are matched by test packets (**show access-lists, show ip access-lists**).

Step 3. Analyze the ACLs to predict which packets should match the ACL, focusing on the following points:

- **A.** Remember that the ACL uses first-match logic.
- **B.** Consider using the (possibly) faster math described in the ICND1 book, Chapter 22, “Basic IP Access Control Lists,” to find the range of addresses matched by an ACL command: Add the address and wildcard mask to find the end of the numeric range.
- **C.** Note the direction of the packet in relation to the server (going to the server, coming from the server). Make sure that the packets have particular values as either the source IP address and port, or as the destination IP address and port, when processed by the ACL enabled for a particular direction (in or out).
- **D.** Remember that the **tcp** and **udp** keywords must be used if the command needs to check the port numbers.
- **E.** Note that ICMP packets do not use UDP or TCP. ICMP is considered to be another protocol matchable with the **icmp** keyword (instead of **tcp** or **udp**).
- **F.** Instead of using the implicit **deny** any at the end of each ACL, use an explicit configuration command to deny all traffic at the end of the ACL so that the **show** command counters increment when that action is taken.

If you suspect ACLs are causing a problem, the first problem-isolation step is to find the location and direction of the ACLs. The fastest way to do this is to look at the output of the **show running-config** command and to look for **ip access-group** commands under each interface. However, in some cases, enable mode access may not be allowed, and **show** commands are required. In that case, another way to find the interfaces and direction for any IP ACLs is the **show ip interfaces** command, as shown in Example 5-8.

Example 5-8. Sample show ip interface **Command**

Click here to view code image

```
R1>show ip interface s0/0/1
Serial0/0/1 is up, line protocol is up
Internet address is 10.1.2.1/24
Broadcast address is 255.255.255.255
Address determined by setup command
MTU is 1500 bytes
Helper address is not set
Directed broadcast forwarding is disabled
Multicast reserved groups joined: 224.0.0.9
Outgoing access list is not set
Inbound access list is 102
! roughly 26 more lines omitted for brevity
```

Note that the command output lists whether an ACL is enabled, in both directions, and which ACL it is. The example shows an abbreviated version of the **show ip interface S0/0/1** command, which lists messages for just this one interface. The **show ip interface** command would list the same messages for every interface in the router.

Step 2 then says that the contents of the ACL must be found. Again, the quickest way to look at the ACL is to use the **show running-config** command. If not available, the **show access-lists** and **show ip access-lists** commands list the same details shown in the configuration commands and a counter for the number of packets matching each line in the ACL. Example 5-9 shows an example.

Example 5-9. show ip access-lists **Command Example**

Click here to view code image

```
R1# show ip access-lists
Extended IP access list 102
10 permit ip 10.1.2.0 0.0.0.255 10.1.4.0 0.0.1.255 (15 matches)
```

After the locations, directions, and configuration details of the various ACLs have been discovered in Steps 1 and 2, the hard part begins—interpreting what the ACL really does.

Of particular interest is the last item in the troubleshooting tips list, item 3F. In the ACL shown in Example 5-9, some packets (15 so far) have matched the single configured **access-list** statement in ACL 102. However, some packets have probably been denied because of the implied deny all packets logic at the end of an ACL. If you configure the **access-list 102 deny ip any any** command at the end of the ACL, which explicitly matches all packets and discards them, the **show ip access-lists** command would then show the number of packets being denied at the end of the ACL.

Finally, as a reminder about interpreting ACL commands, when you know the command comes from a router, it is easy to decide the range of addresses matched by an address and wildcard mask. The low end of the range is the address (the first number), and the high end of the range is the sum of the address and wildcard mask. For instance, with ACL 102 in Example 5-9, which is obviously configured in some router, the ranges are as follows:

Source 10.1.2.0, wildcard 0.0.0.255: Matches from 10.1.2.0 through 10.1.2.255

Destination 10.1.4.0, wildcard 0.0.1.255: Matches from 10.1.4.0 through 10.1.5.255

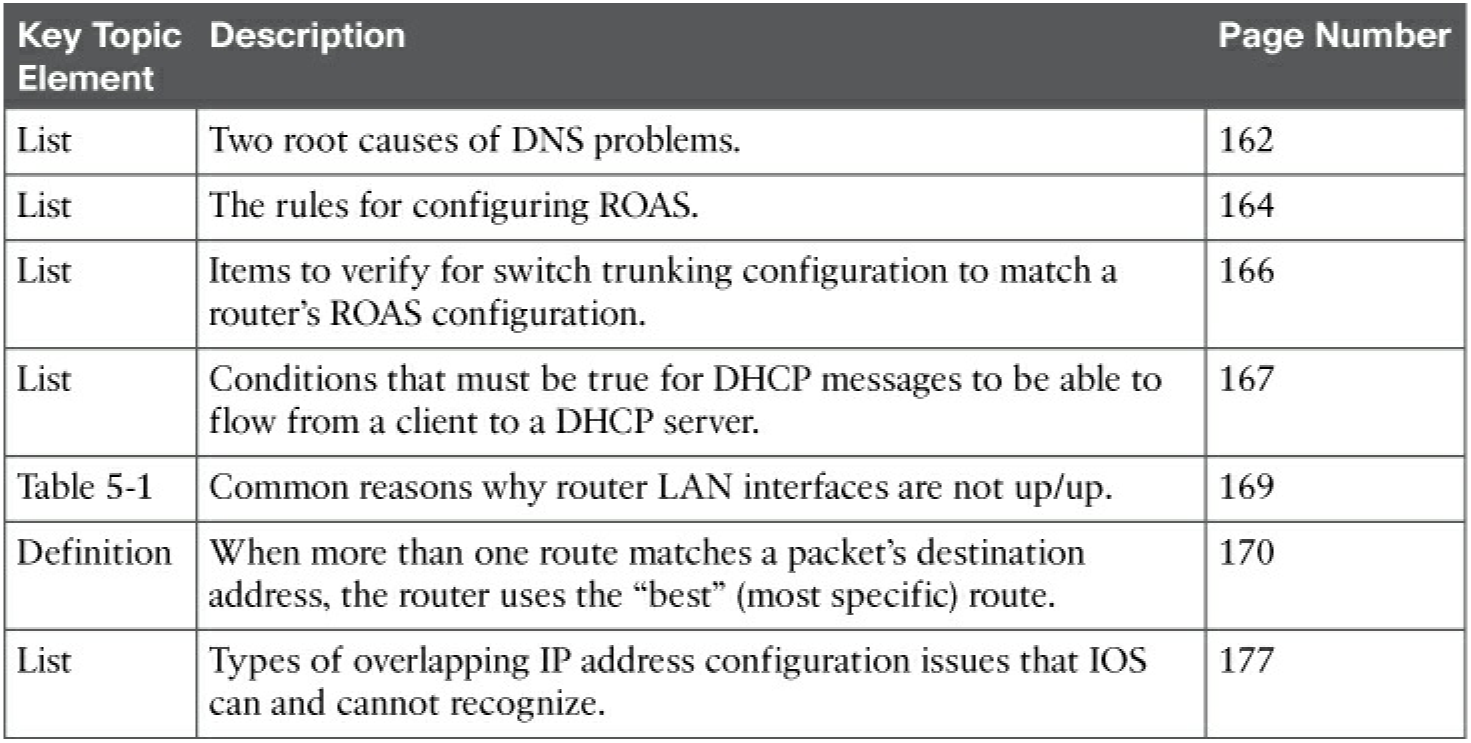
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 5-4 lists these key topics and where each is discussed.

Key Topic

Table 5-4. Key Topics for Chapter 5



Key Topic Element	Description	Page Number
List	Two root causes of DNS problems.	162
List	The rules for configuring ROAS.	164
List	Items to verify for switch trunking configuration to match a router's ROAS configuration.	166
List	Conditions that must be true for DHCP messages to be able to flow from a client to a DHCP server.	167
Table 5-1	Common reasons why router LAN interfaces are not up/up.	169
Definition	When more than one route matches a packet's destination address, the router uses the "best" (most specific) route.	170
List	Types of overlapping IP address configuration issues that IOS can and cannot recognize.	177

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix D, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix E, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22 directs you in how to use these terms for late-stage preparation for the exam.

Chapter 6. Creating Redundant First-Hop Routers

This chapter covers the following exam topics:

IP Routing Technologies

Recognize high availability (FHRP)

- VRRP
- HSRP
- GLBP

Businesses rely on their networks to get their work done. Some businesses rely more on the network than others, with a direct connection between network outages and lost revenue. For instance, when the network is down, some companies lose customers, or lose sales, or they cannot ship their goods to market, affecting sales volume in the future. Companies can design their networks to use redundancy—extra devices and extra links—so that when a device fails, or a link fails, the network still works. The extra devices may cost more money, but the cost may be justified, given the cost of an outage.

Networks that have redundant devices and links sometimes require additional protocols to deal with changes to how the network functions with the added redundancy. This chapter discusses one such class of protocols, called First Hop Redundancy Protocol (FHRP).

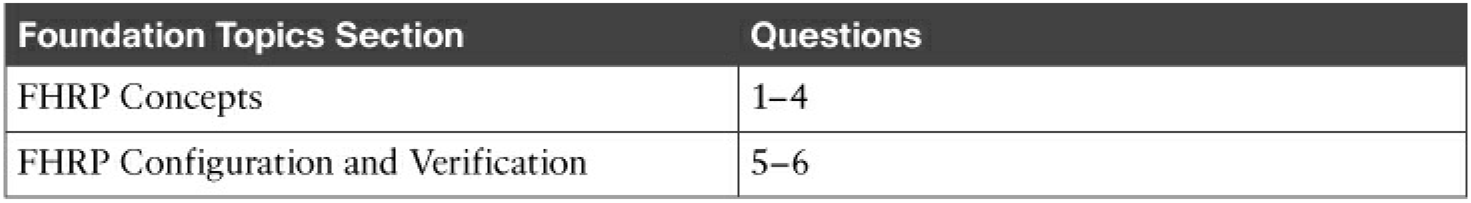
FHRPs allow network engineers to install multiple routers in a subnet, which collectively act as a single default router. The FHRP makes the routers appear like a single default router to the hosts, letting the hosts be completely unaware of the redundant routers while receiving the benefits of that redundancy. The routers exchange messages to coordinate which router does the work and how to recognize a router problem and take over the function of the other router when needed.

This chapter breaks the content into two major sections. The first looks at the reasons for FHRP protocols, and introduces the three FHRP options: Hot Standby Routing Protocol (HSRP), Virtual Router Redundancy Protocol (VRRP), and Gateway Load Balancing Protocol (GLBP). The second half looks at the configuration and verification of HSRP and GLBP.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 6-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
FHRP Concepts	1–4
FHRP Configuration and Verification	5–6

1. R1 and R2 attach to the same Ethernet VLAN, with subnet 10.1.19.0/25, with addresses 10.1.19.1 and 10.1.19.2, respectively, configured with the **ip address** interface subcommand. Host A refers to 10.1.19.1 as its default router, and host B refers to 10.1.19.2 as its default router. The routers do not use an FHRP. Which of the following are problems for this LAN?
   - **a.** The design breaks IPv4 addressing rules, because two routers cannot connect to the same LAN subnet.
   - **b.** If one router fails, neither host can send packets off-subnet.
   - **c.** If one router fails, both hosts will use the one remaining router as default router.
   - **d.** If one router fails, the host that uses that router as a default router cannot send packets off-subnet.
2. R1 and R2 attach to the same Ethernet VLAN, with subnet 10.1.19.0/25, with addresses 10.1.19.1 and 10.1.19.2, respectively, configured with the **ip address** interface subcommand. The routers use an FHRP. Host A and host B attach to the same LAN and have correct default router settings per the FHRP configuration. Which of the following statements is true for this LAN?
   - **a.** The design breaks IPv4 addressing rules, because two routers cannot connect to the same LAN subnet.
   - **b.** If one router fails, neither host can send packets off-subnet.
   - **c.** If one router fails, both hosts will use the one remaining router as default router.
   - **d.** If one router fails, only one of the two hosts will still be able to send packets off-subnet.
3. Which of the following FHRP options uses an active/active approach (per subnet) to support first-hop (default router) traffic when implemented with two routers on the same LAN?
   - **a.** GLBP
   - **b.** HSRP
   - **c.** BFD
   - **d.** VRRP
4. R1 and R2 attach to the same Ethernet VLAN, with subnet 10.1.19.0/25, with addresses 10.1.19.1 and 10.1.19.2,

respectively, configured with the **ip address** interface subcommand. The routers use HSRP. The network engineer prefers to have R1 be the default router when both R1 and R2 are up. Which of the following are the likely default router setting for hosts in this subnet?

a. 10.1.19.1

b. 10.1.19.2

c. Another IP address in subnet 10.1.19.0/25 other than 10.1.19.1 and 10.1.19.2

d. A hostname that the FHRP mini-DNS will initially point to 10.1.19.1

5. The following text lists output taken from router R3, which is using HSRP. Subnet 10.1.12.0 uses mask 255.255.255.0. Based on the output of this command, which of the following answers is true?

Click here to view code image

```
R3# show standby brief
Interface Grp Pri P State Active Standby Virtual IP
Gi0/0 1 105 Active local 10.1.12.1 10.1.12.2
```

a. Hosts with a default router setting of 10.1.12.1 are sending their packets to router R3.

b. Hosts with a default router setting of 10.1.12.2 are sending their packets to router R3.

c. Router R3 has an **ip address 10.1.12.2 255.255.255.0** command configured on its G0/0 interface.

d. Router R3 has an **ip address 10.1.12.1 255.255.255.0** command configured on its G0/0 interface.

6. The following text lists output taken from router R3, which is using GLBP. Subnet 10.1.12.0 uses mask 255.255.255.0. Based on the output of this command, which of the following answers is true?

Click here to view code image

```
R3# show glbp brief
Interface Grp Fwd Pri State Address Active router Standby router
Gi0/0 1 - 100 Standby 10.1.12.2 10.1.12.4 local
Gi0/0 1 1 - Active 0007.b400.0101 local -
Gi0/0 1 2 - Listen 0007.b400.0102 10.1.12.4 -
```

a. R3 is the active virtual gateway.

b. The router with an interface IP address of 10.1.12.2, configured with the **ip address** command, is the active virtual gateway.

c. The router with an interface IP address of 10.1.12.4, configured with the **ip address** command, is the active virtual gateway.

d. The output does not identify the active virtual gateway, because the AVG concept is a VRRP concept, not GLBP.

Answers to the "Do I Know This Already?" quiz:

1 D **2** C **3** A **4** C **5** B **6** C

Foundation Topics

FHRP Concepts

When networks use a design that includes redundant routers, switches, LAN links, and WAN links, in some cases other protocols are required to both take advantage of that redundancy and to prevent problems caused by it. For instance, imagine a WAN with many remote branch offices. If each remote branch has two WAN links connecting it to the rest of the network, those routers can use an IP routing protocol to pick the best routes. When one WAN link fails, the routing protocol can learn routes that all happen to use the one remaining WAN link, taking advantage of the redundant link.

As another example, consider a LAN with redundant links and switches, as discussed in Chapters 1, "Spanning Tree Protocol Concepts," and 2, "Spanning Tree Protocol Implementation," of this book. Those LANs have problems unless the switches use Spanning Tree Protocol (STP). STP prevents the problems created by frames that loop through those extra redundant paths in the LAN.

This chapter examines yet another type of protocol that helps when a network uses some redundancy, this time with redundant default routers. When two or more routers connect to the same LAN subnet, all those routers could be used as the default router for the hosts in the subnet. However, to make the best use of the redundant default routers, another protocol is needed. The term *First Hop Redundancy Protocol* (FHRP) refers to the category of protocols that can be used so that the hosts take advantage of redundant routers in a subnet.

The first of two major sections of the chapter discusses the major concepts behind how different FHRPs work. This section begins by discussing a network's need for redundancy in general and the need for redundant default routers. It then shows how the three available FHRP options can each solve the problems that occur when using redundant default routers.

The Need for Redundancy in Networks

Networks need redundant links to improve the availability of the network. Eventually, something in the network will fail. A router power supply might fail, or a cable might break, or a switch might lose power. And those WAN links, drawn as simple lines in most drawings in this book, are actually the most complicated physical parts of the network, with many individual parts that can fail as well.

Depending on the design of the network, the failure of a single component might mean an outage that affects at least some part of the user population. Network engineers refer to any one component that, if it fails, brings down that part of the network as a *single point of failure*. For instance, in Figure 6-1, the LANs appear to have some redundancy, whereas the WAN does not. If most of the traffic flows between sites, many single points of failure exist, as shown in the figure.

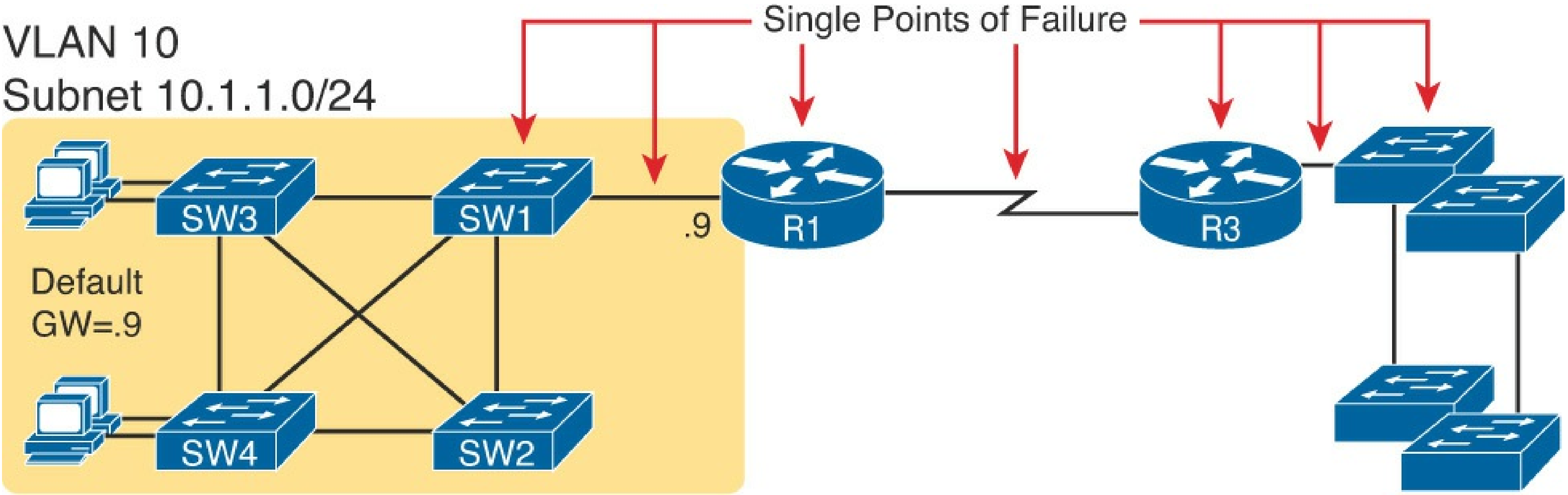


Figure 6-1. R1 and the One WAN Link as Single Points of Failure

The figure notes several components as a single point of failure. If any one of the noted parts of the network fail, packets cannot flow from the left side of the network to the right.

Generally speaking, to improve availability the network engineer first looks at a design and finds the single points of failure. Then, the engineer chooses where to add to the network, so that one (or more) single points of failure now have redundant options, increasing availability. In particular, the engineer:

- Adds redundant devices and links
- Implements any necessary functions that take advantage of the redundant device or link

For instance, of all the single points of failure in Figure 6-1, the most expensive over the long term would likely be the WAN link, because of the ongoing monthly charge. However, statistically, the WAN links are the most likely component to fail. So, a reasonable upgrade from the network in Figure 6-1 would be to add a WAN link and possibly even connect to another router on the right side of the network, as shown in Figure 6-2.

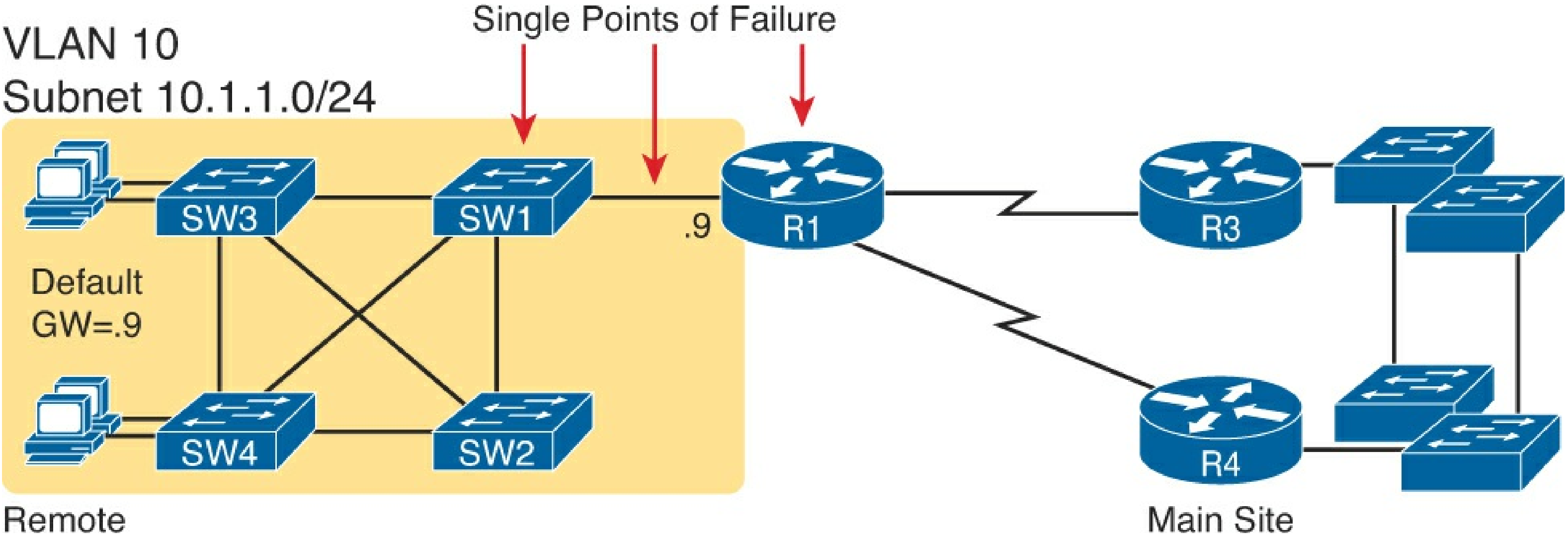


Figure 6-2. Higher Availability, But with R1 Still as a Single Point of Failure

Many real enterprise networks follow designs like Figure 6-2, with one router at each remote site, two WAN links connecting back to the main site, and with redundant routers at the main site (on the right side of the figure). Compared to Figure 6-1, the design in Figure 6-2 has fewer single points of failure. Of the remaining single points of failure, a risk remains, but it is a calculated risk. For many outages, a reload of the router solves the problem, and the outage is short. But the risk still exists that the switch or router hardware fails completely and requires time to deliver a replacement device on-site before that site can work again.

For enterprises that can justify more expense, the next step in higher availability for that remote site is to protect against those catastrophic router and switch failures. In this particular design, adding one router on the left side of the network in Figure 6-2 removes all the single points of failure that had been noted earlier. Figure 6-3 shows the design with a second router, which connects to a different LAN switch so that SW1 is also no longer a single point of failure.

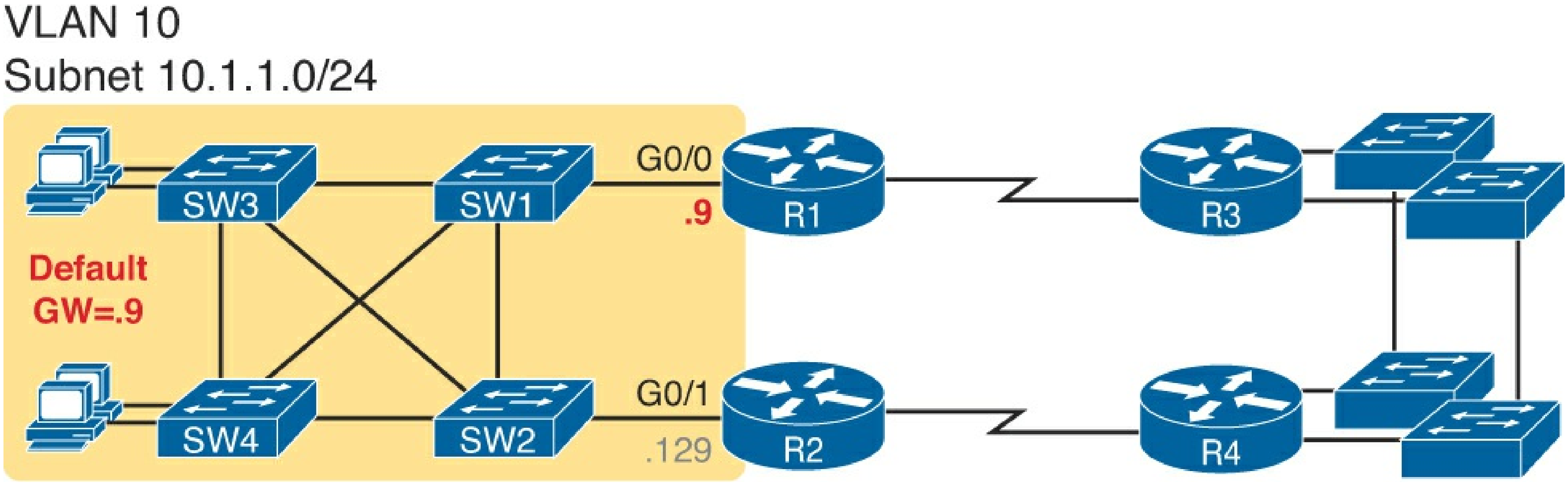


Figure 6-3. Removing All Single Points of Failure from the Network Design

> **Note**
>
> Medium to large enterprise networks work hard at striking a balance of high-availability features versus the available budget dollars. The Cisco website has many design documents that discuss tradeoffs in high-availability design. If interested in learning more, search cisco.com for "high availability campus network design."

The Need for a First Hop Redundancy Protocol

Now back to the topic of this chapter. Of the designs shown so far in this chapter, only Figure 6-3's design has two routers on the LAN of the left side of the figure, specifically the same VLAN and subnet. While having the redundant routers on the same subnet helps, the network needs to use an FHRP when these redundant routers exist.

To see the need and benefit of using an FHRP, first think about how these redundant routers could be used as default routers by the hosts in VLAN 10/subnet 10.1.1.0/24. The host logic will remain unchanged, so each host has a single default router setting. So, some design options for default router settings include the following:

- All hosts in the subnet use R1 (10.1.1.9) as their default router, and they statically reconfigure their default router setting to R2's 10.1.129 if R1 fails.
- All hosts in the subnet use R2 (10.1.1.129) as their default router, and they statically reconfigure their default router setting to R1's 10.1.1.9 if R2 fails.
- Half the hosts use R1, and half use R2, as default router, and if either router fails, that half of the users statically reconfigure their default router setting.

To make sure the concept is clear, Figure 6-4 shows this third option, with half the hosts using R1, and the other half using R2. The figure removes all the LAN switches just to unclutter the figure. Hosts A and B use R1 as default router, and hosts C and D use R2 as default router.

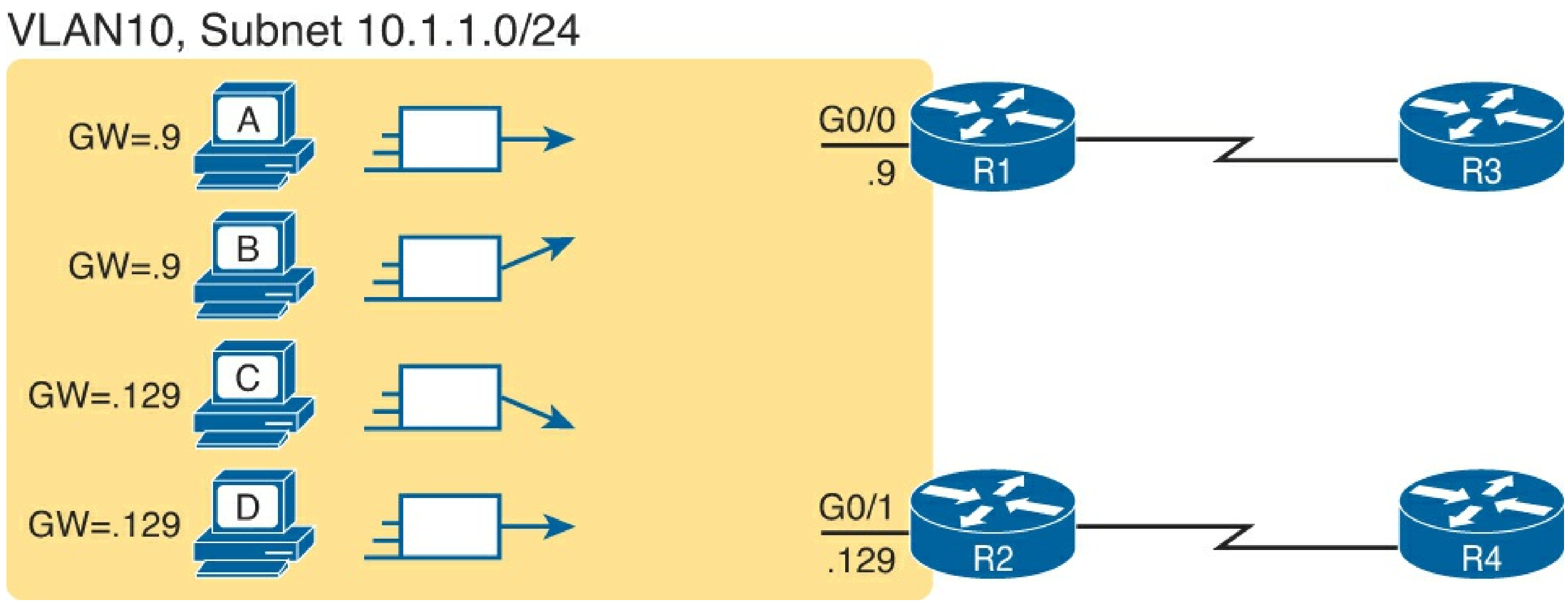


Figure 6-4. Balancing Traffic by Assigning Different Default Routers to Different Clients

All of these options have a problem: The users have to take action. They have to know an outage occurred. They have to know how to reconfigure their default router setting. And they have to know when to change it back to the original setting.

FHRPs make this design work better. The two routers appear to be a single default router. The users never have to do anything: Their default router setting remains the same, and their ARP table even remains the same.

To allow the hosts to remain unchanged, the routers have to do some more work, as defined by one of the FHRP protocols. Generically, each FHRP makes the following happen:

Key Topic

1. All hosts act like they always have, with one default router setting that never has to change.
2. The default routers share a virtual IP address in the subnet, defined by the FHRP.
3. Hosts use the FHRP virtual IP address as their default router address.
4. The routers exchange FHRP protocol messages, so that both agree as to which router does what work at any point in time.
5. When a router fails, or has some other problem, the routers use the FHRP to choose which router takes over responsibilities from the failed router.

The Three Solutions for First-Hop Redundancy

The term *First Hop Redundancy Protocol* does not name any one protocol. Instead, it names a family of protocols that fill the same role. For a given network, like the left side of Figure 6-4, the engineer would pick one of the protocols from the FHRP family.

> **Note**
>
> *First Hop* is a reference to the default router being the first router, or first router hop, through which a packet must pass.

Table 6-2 lists the three FHRP protocols in chronological order, based on when these were first used. Cisco first introduced the proprietary Hot Standby Router Protocol (HSRP), and it worked well for many of their customers. Later, the IETF developed an RFC for a very similar protocol, Virtual Router Redundancy Protocol (VRRP). Finally, Cisco developed a more robust option, Gateway Load Balancing Protocol (GLBP).

Key Topic

Table 6-2. Three FHRP Options

Acronym	Full Name	Origin	Redundancy Approach	Load Balancing
HSRP	Hot Standby Router Protocol	Cisco	Active/standby	Per subnet
VRRP	Virtual Router Redundancy Protocol	IETF (RFC 5798)	Active/standby	Per subnet
GLBP	Gateway Load Balancing Protocol	Cisco	Active/active	Per host

The next few pages walk through the concepts of how HSRP works, followed by GLBP. HSRP and VRRP have many similarities, at least to the depth discussed in this book, so this section uses HSRP rather than VRRP as an example. These upcoming topics explain the meaning of the different approaches to redundancy (active/standby and active/active) and the load balancing differences as well.

HSRP Concepts

HSRP operates with an active/standby model (also more generally called *active/passive*). HSRP allows two (or more) routers to cooperate, all being willing to act as the default router. However, at any one time, only one router actively supports the end-user traffic. The packets sent by hosts to their default router flow to that one active router. Then, the other routers, with an HSRP standby state, sit there patiently waiting to take over should the active HSRP router have a problem.

The HSRP active router implements a virtual IP address and matching virtual MAC address. This virtual IP address exists as part of the HSRP configuration, which is an additional configuration item compared to the usual **ip address** interface subcommand. This virtual IP address is in the same subnet as the interface IP address, but it is a different IP address. The router then automatically creates the virtual MAC address. All the cooperating HSRP routers know these virtual addresses, but only the HSRP active router uses these addresses at any one point in time.

Hosts refer to the virtual IP address as their default router address, instead of any one router's interface IP address. For instance, in Figure 6-5, R1 and R2 use HSRP. The HSRP virtual IP address is 10.1.1.1, with the virtual MAC address referenced as VMAC1 for simplicity's sake.

Key Topic

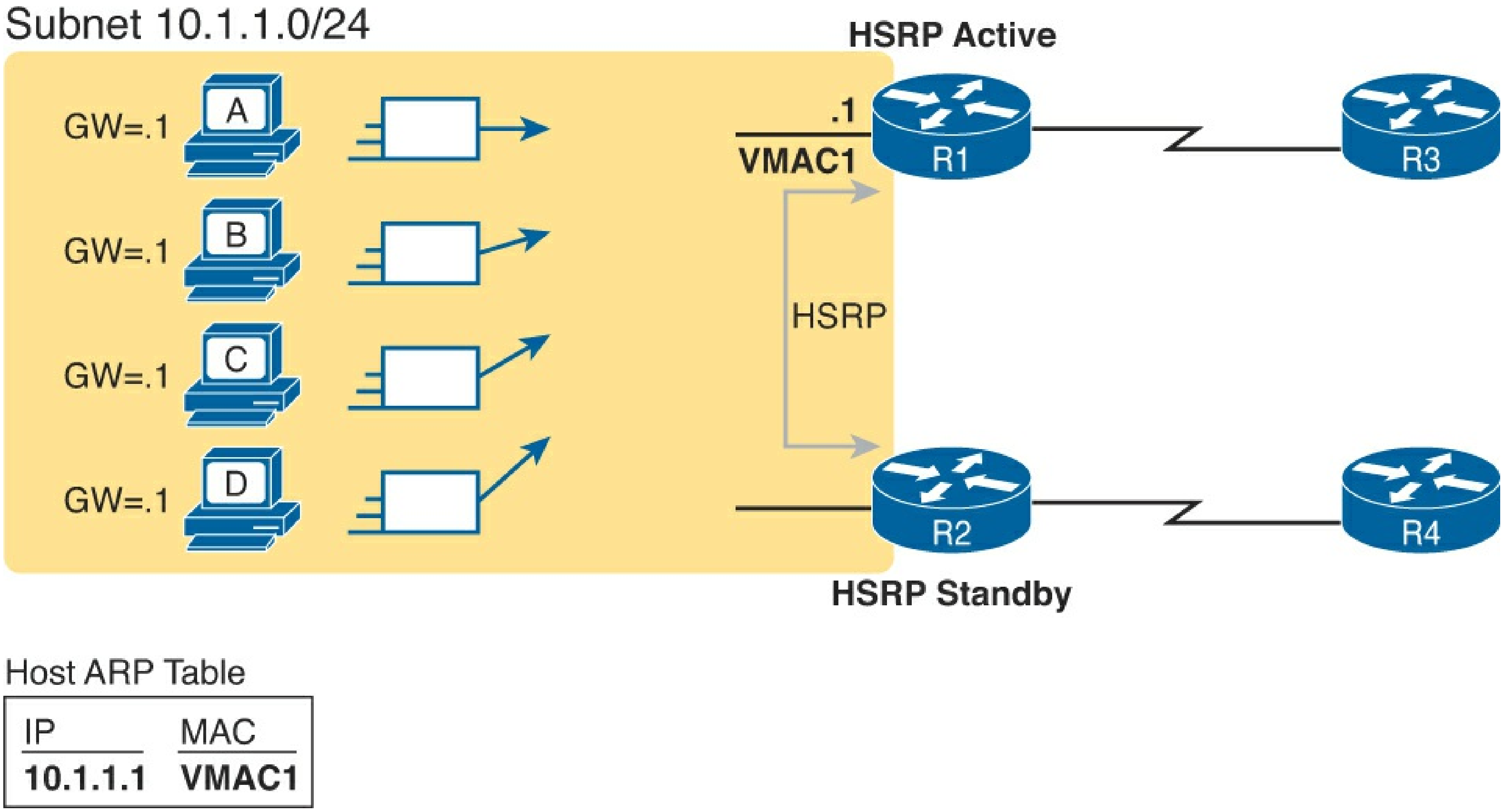


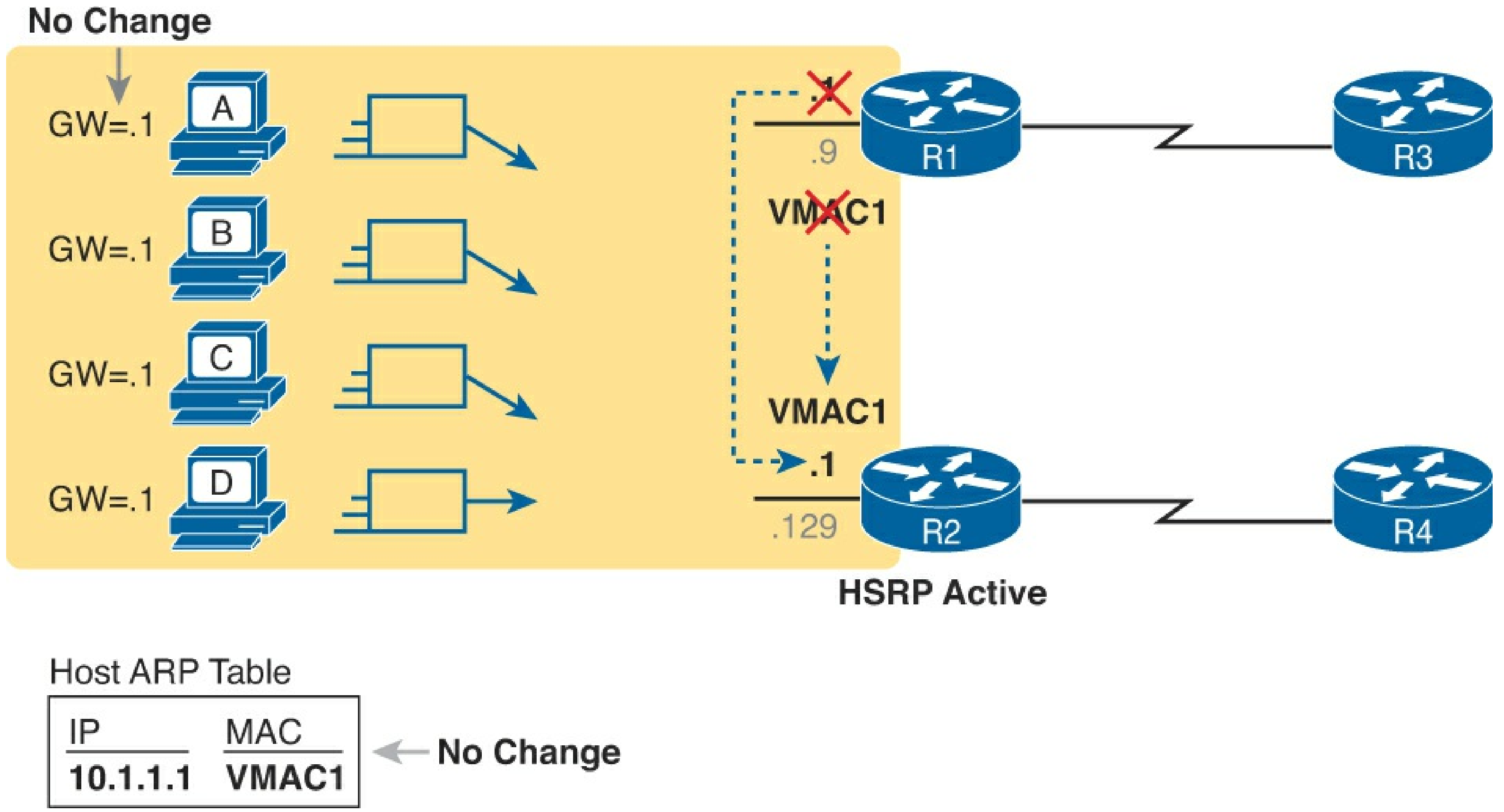
Figure 6-5. All Traffic Goes to .1 (R1, Which Is Active); R2 Is Standby

HSRP Failover

HSRP on each router has some work to do to make the network function as shown in Figure 6-5. The two routers need HSRP configuration, including the virtual IP address. The two routers send HSRP messages to each other to negotiate and decide which router should currently be active, and which should be standby. Then, the two routers continue to send messages to each other so that the standby router knows when the active router fails so that it can take over as the new active router.

Figure 6-6 shows the result when the R1, the HSRP active router in Figure 6-5, fails. R1 quits using the virtual IP and MAC address, while R2, the new active router, starts using these addresses. The hosts do not need to change their default router settings at all, with traffic now flowing to R2 instead of R1.

Key Topic



IP	MAC
10.1.1.1	VMAC1

Figure 6-6. Packets Sent Through R2 (New Active) Once It Takes Over for Failed R1

When the failover happens, some changes do happen, but none of those changes happen on the hosts. The host keeps the same default router setting, set to the virtual IP address (10.1.1.1 in this case). The host's ARP table does not have to change either, with the HSRP virtual MAC being listed as the MAC address of the virtual router.

When the failover occurs, changes happen on both the routers and the LAN switches. Clearly, the new active router has to be ready to receive packets (encapsulated inside frames) using the virtual IP and MAC addresses. However, the LAN switches, hidden in the last few figures, formerly sent frames destined for VMAC1 to router R1. Now the switches must know to send the frames to the new active router, R2.

To make the switches change their MAC address table entries for VMAC1, R2 sends an Ethernet frame with VMAC1 as the source MAC address. The switches, as normal, learn the source MAC address (VMAC1), but with new ports that point toward R2. The frame is also a LAN broadcast, so all the switches learn a MAC table entry for VMAC1 that leads toward R2. (By the way, this Ethernet frame holds an ARP Reply message, called a gratuitous ARP, because the router sends it without first receiving an ARP Request.)

HSRP Load Balancing

The active/standby model of HSRP means that in one subnet all hosts send their off-subnet packets through only one router. In other words, the routers do not share the workload, with one router handling all the packets. For instance, back in Figure 6-5, R1 was the active router, so all hosts in the subnet sent their packets through R1, and none of the hosts in the subnet sent their packets through R2.

HSRP does support load balancing by preferring different routers to be the active router in different subnets. Most sites that require a second router for redundancy are also big enough to use several VLANs and subnets and the site. The two routers will likely connect to all the VLANs, acting as the default router in each VLAN. HSRP then can be configured to prefer one router as active in one VLAN, and another router as active in another VLAN, balancing the traffic.

For instance, Figure 6-7 shows a redesigned LAN, now with two hosts in VLAN 1 and two hosts in VLAN 2. Both R1 and R2 connect to the LAN, and both use a VLAN trunking and router-on-a-stick (ROAS) configuration. Both routers use HSRP in each of the two subnets, supporting each other. However, on purpose, R1 has been configured so that it wins the negotiation to become HSRP active in VLAN 1, and R2 has been configured to win in VLAN 2.

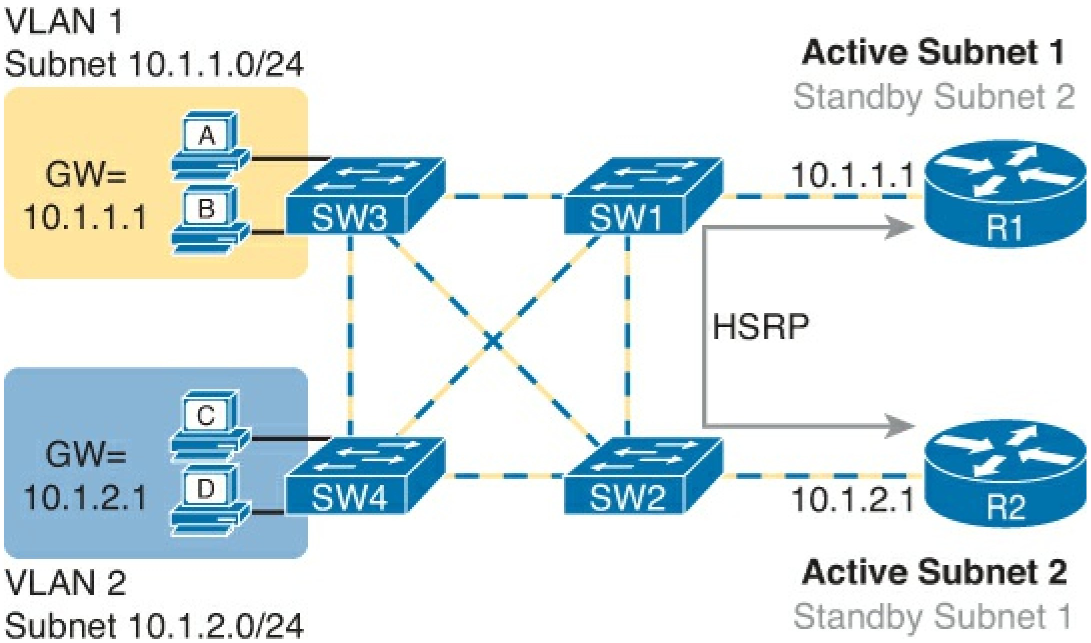


Figure 6-7. Load Balancing with HSRP by Using Different Active Routers per Subnet

Note that by having each router act as the HSRP active router in some subnets, the design makes use of both routers and both WAN links.

> **Note**
>
> For designs that use Layer 3 switches, the Layer 3 switches act as the default router of the hosts. In that case, the HSRP configuration goes on the Layer 3 switch. Figure 6-7 shows the alternative, which is to use VLAN trunking on the routers with Layer 2 switches in the LAN.

GLBP Concepts

HSRP and VRRP, which were introduced before Gateway Load Balancing Protocol (GLBP), balanced the packet load per subnet, as shown in Figure 6-7. However, because traffic loads vary unpredictably from subnet to subnet, Cisco wanted an FHRP option with better load-balancing options than just the per-subnet load balancing of HSRP and VRRP. To meet that need, Cisco introduced GLBP.

GLBP balances the packet load per host by using an active/active model in each subnet. Each GLBP router in a subnet receives off-subnet packets from some of the hosts in the subnet. Each host still remains unaware of the FHRP, allowing the hosts to configure the same default gateway/router setting and for the hosts to make no changes when a router fails.

GLBP creates a world that at first glance looks like HSRP, but with a few twists that let GLBP balance the traffic. Like HSRP, all the routers configure a virtual IP address, which is the IP address used by hosts as their default router. Like with HSRP, hosts use a default router setting that points to the virtual IP address, and that setting does not need to change. GLBP differs from HSRP with regard to the MAC addresses it uses and the ARP process, because GLBP actually uses ARP Reply messages to balance traffic from different hosts through different routers.

With GLBP, one router acts in a special role called the *active virtual gateway* (AVG). The AVG replies to all ARP requests for the virtual IP address. Each router has a unique virtual MAC address, so that the AVG can reply to some ARP Requests with one virtual MAC, and some with the other. As a result, some hosts in the subnet send frames to the Ethernet MAC address of one of the routers, with other hosts sending their frames to the MAC address of the second router.

As an example, Figure 6-8 shows the process by which a GLBP balances traffic for host A based on the Address Resolution Protocol (ARP) Reply sent by the AVG (R1). The figure uses the same IP addresses as earlier HSRP examples with Figures 6-5 and 6-6. The two routers support virtual IP address 10.1.1.1, with the hosts using that address as their default router setting.

Key Topic

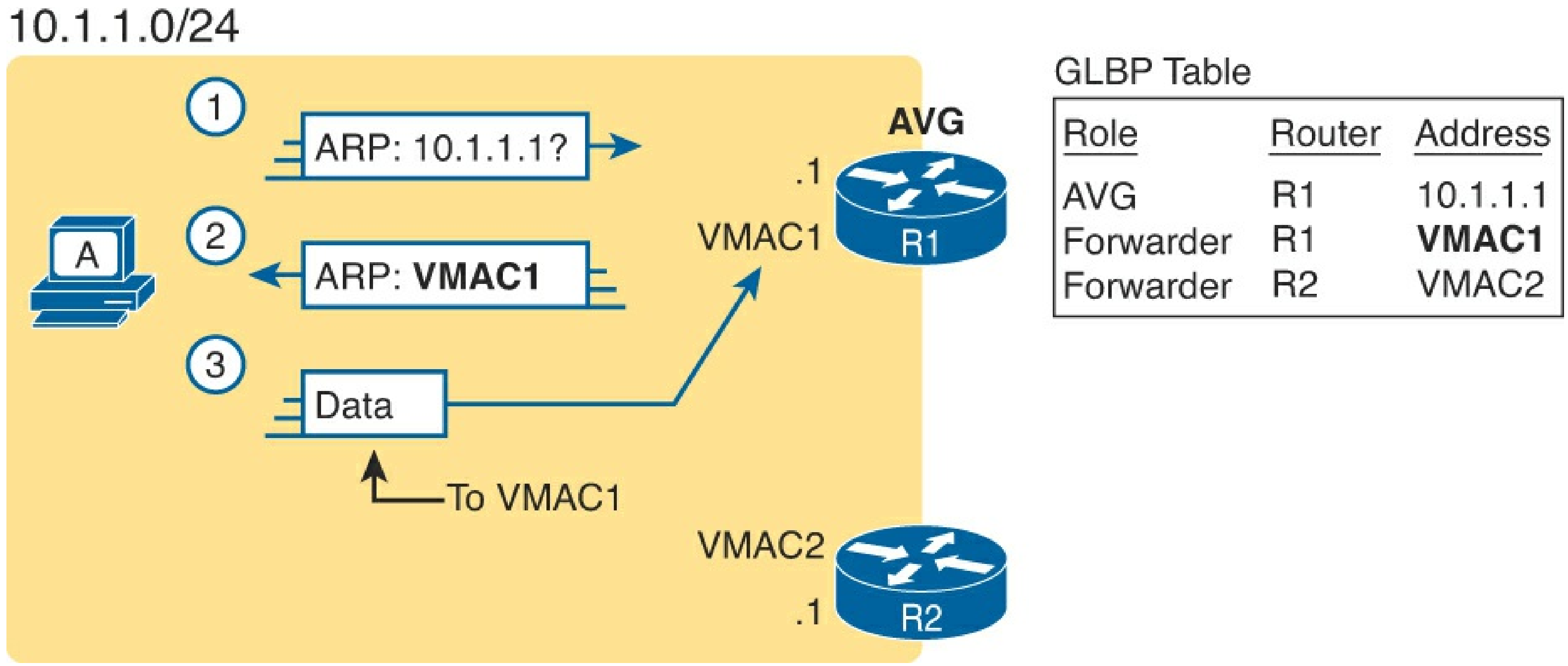

10.1.1.0/24
1
ARP: 10.1.1.1?
2
ARP: VMAC1
3
Data
To VMAC1
A
AVG
.1
VMAC1
R1
VMAC2
.1
R2
GLBP Table
Role Router Address
AVG R1 10.1.1.1
Forwarder R1 VMAC1
Forwarder R2 VMAC2

Figure 6-8. GLBP Directs Host A by Sending Back ARP Reply with R1's MAC1

The figure shows three messages, top to bottom, with the following action:

1. Host A has no ARP table entry for its default router, 10.1.1.1, so host A sends an ARP Request to learn 10.1.1.1's MAC address.
2. The GLBP AVG, R1 in this case, sends back an ARP Reply. The AVG chooses to include its own virtual MAC address in the ARP Reply, VMAC1.
3. Future IP packets sent by host A are encapsulated in Ethernet frames, destined to VMAC1, so that they arrive at R1.

From now on, host A sends off-subnet packets to R1 due to host A's ARP table entry for its default gateway (10.1.1.1). Host A's ARP table entry for 10.1.1.1 now refers to a MAC address on R1 (VMAC1), so packets host A sends off-subnet flow through R1.

To balance the load, the AVG answers each new ARP Request with the MAC addresses of alternating routers. Figure 6-9 continues the load-balancing effect with the ARP Request for 10.1.1.1 coming from host B. The router acting as AVG (R1) still sends the ARP Reply, but this time with R2's virtual MAC (VMAC2).

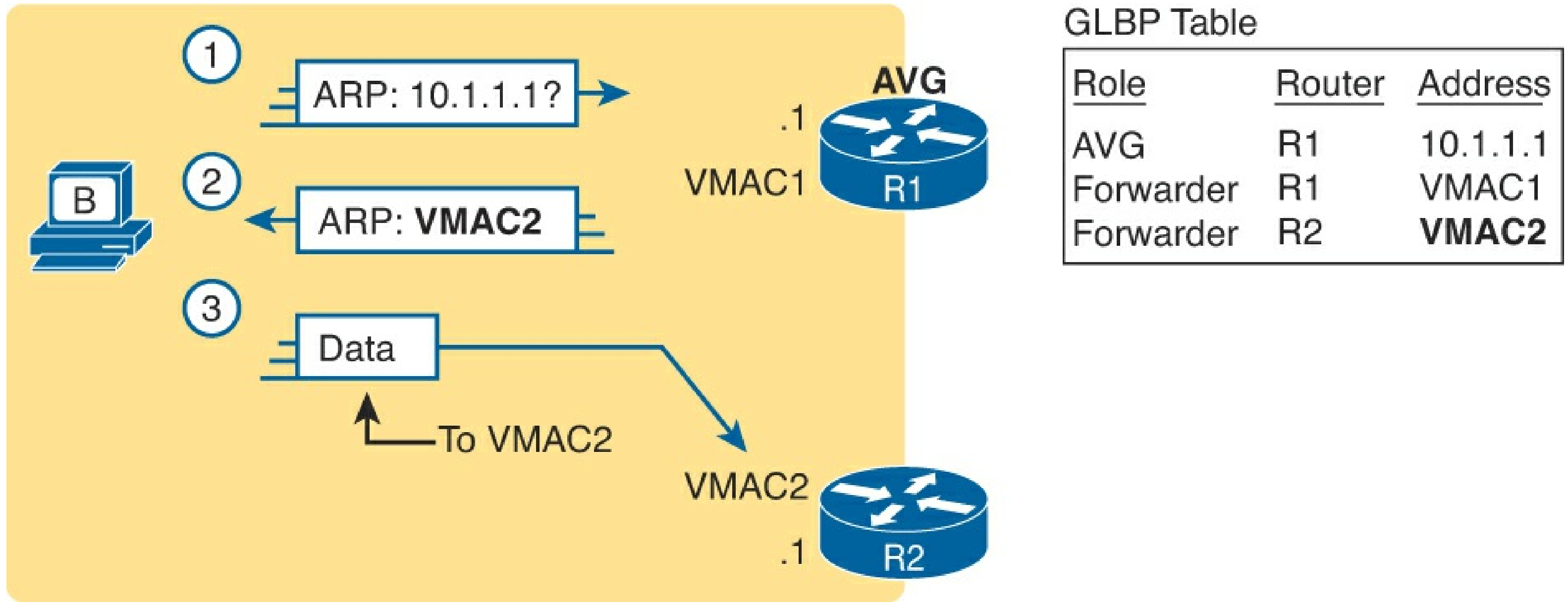

1
ARP: 10.1.1.1?
2
ARP: VMAC2
3
Data
To VMAC2
B
AVG
.1
VMAC1
R1
VMAC2
.1
R2
GLBP Table
Role Router Address
AVG R1 10.1.1.1
Forwarder R1 VMAC1
Forwarder R2 VMAC2

Figure 6-9. GLBP Directs Host B by Sending Back ARP Reply with R2's VMAC2

Here are the steps in the figure:

1. Host B sends an ARP Request to learn 10.1.1.1's MAC address.
2. The GLBP AVG (R1) sends back an ARP Reply, listing VMAC2, R2's virtual MAC address.
3. For future packets sent off-subnet, host B encapsulates the packets in Ethernet frames, destined to VMAC2, so that they arrive at R2.

The process shown in Figures 6-8 and 6-9 balances the traffic, per host, but the routers must also be ready to take over for the other router if it fails. GLBP refers to each router as a forwarder. When all is well, each router acts as forwarder for their own virtual MAC address, but it listens to GLBP messages to make sure the other forwarders are still working. If another forwarder fails, the still-working forwarder takes over the failed forwarder's virtual MAC address role and continues to forward traffic.

FHRP Configuration and Verification

This second major section of this chapter shows the configuration for basic functions of both HSRP and GLBP, with the matching **show** commands. The goal of this section is to show enough of the operation of each tool to reinforce the concepts discussed in the first section.

Configuring and Verifying HSRP

HSRP configuration requires only one command on the two (or more) routers that want to share default router responsibilities with HSRP: the **standby** *group* **ip** *virtual-ip* interface subcommand. The first value defines the HSRP group number, which must match on both routers. The group number lets one router support multiple HSRP groups at a time, and it allows the routers identify each other based on the group. The command also configures the virtual IP address shared by the routers in the same group.

Example 6-1 shows a configuration example, matching the HSRP examples related to Figures 6-5 and 6-6. Both routers use group 1, with virtual IP address 10.1.1.1, with the **standby 1 ip 10.1.1.1** interface subcommand.

Example 6-1. HSRP Configuration on R1 and R2, Sharing IP Address 10.1.1.1

Click here to view code image

```
R1# show running-config
! Lines omitted for brevity
interface GigabitEthernet0/0
ip address 10.1.1.9 255.255.255.0
standby version 2
standby 1 ip 10.1.1.1
standby 1 priority 110
standby 1 name HSRP-group-for-book
```

```
! The following configuration, on R2, is identical except for the priority,
! the interface IP address, and the HSRP priority
R2# show running-config
! Lines omitted for brevity
interface GigabitEthernet0/0
ip address 10.1.1.129 255.255.255.0
standby version 2
standby 1 ip 10.1.1.1
standby 1 name HSRP-group-for-book
```

The configuration shows other optional parameters, as well. For instance, R1 has a priority of 110 in this group, and R2 defaults to 100. With HSRP, if the two routers are brought up at the same time, the router with the higher priority wins the election to become the active router. The configuration also shows a name that can be assigned to the group (when using **show** commands) and a choice to use HSRP Version 2.

Once configured, the two routers negotiate the HSRP settings and choose which router will currently be active and which will be standby. With the configuration as shown, R1 will win the election and become active because of its higher (better) priority. Both routers reach the same conclusion, as confirmed with the output of the **show standby brief** command on both R1 and R2 in Example 6-2.

Example 6-2. HSRP Status on R1 and R2 with show standby brief

Click here to view code image

```
! First, the group status as seen from R1
R1# show standby brief
P indicates configured to preempt.
|
Interface Grp Pri P State Active Standby Virtual IP
Gi0/0 1 110 Active local 10.1.1.129 10.1.1.1
```

```
! The output here on R2 shows that R2 agrees with R1.
R2# show standby brief
P indicates configured to preempt.
|
Interface Grp Pri P State Active Standby Virtual IP
Gi0/0 1 100 Standby 10.1.1.9 local 10.1.1.1
```

First, look at the Grp column for each command. This lists the HSRP group number, so when looking at output from multiple routers, you need to look at the lines with the same group number to make sure the data relates to that one HSRP group. In this case, both routers have only one group number (1), so it is easy to find the information.

Each line of output lists the local router's view of the HSRP status for that group. In particular, based on the headings, the **show standby brief** command identifies the following:

Key Topic

Interface: The local router's interface on which the HSRP group is configured

Grp: The HSRP group number

Pri: The local router's HSRP priority

State: The local router's current HSRP state

Active: The interface IP address of the currently-active HSRP router (or "local" if the local router is HSRP active)

Standby: The interface IP address of the currently-standby HSRP router (or "local" if the local router is HSRP standby)

Virtual IP: The virtual IP address defined by this group

For instance, following the highlighted text in Example 6-2, R2 believes that its own current state is standby, that the router with interface address 10.1.1.9 is active, with a confirmation that the "local" router (R2, on which this command was issued) is the standby router.

As you can see, the **show standby brief** command actually packs a lot of detail in a single line of output. In comparison, the **show standby** command lists a more detailed description of the current state, while repeating many of the facts from the **show standby brief** command. Example 6-3 shows an example of the new information with the **show standby** command, listing several counters and timers about the HSRP protocol itself, plus the virtual MAC address 0000.0c9f.f001.

Example 6-3. HSRP Status on R1 and R2 with show standby

Click here to view code image

```
R1# show standby
GigabitEthernet0/0 - Group 1 (version 2)
State is Active
6 state changes, last state change 00:12:53
Virtual IP address is 10.1.1.1
Active virtual MAC address is 0000.0c9f.f001
Local virtual MAC address is 0000.0c9f.f001 (v2 default)
Hello time 3 sec, hold time 10 sec
Next hello sent in 1.696 secs
Preemption disabled
Active router is local
Standby router is 10.1.1.129, priority 100 (expires in 8.096 sec)
Priority 110 (configured 110)
Group name is "HSRP-group-for-book" (cfgd)
```

```
! The output here on R2 shows that R2 agrees with R1.
R2# show standby
GigabitEthernet0/0 - Group 1 (version 2)
State is Standby
4 state changes, last state change 00:12:05
Virtual IP address is 10.1.1.1
Active virtual MAC address is 0000.0c9f.f001
Local virtual MAC address is 0000.0c9f.f001 (v2 default)
Hello time 3 sec, hold time 10 sec
Next hello sent in 0.352 secs
Preemption disabled
Active router is 10.1.1.9, priority 110 (expires in 9.136 sec)
MAC address is 0200.0101.0101
Standby router is local
Priority 100 (default 100)
Group name is "HSRP-group-for-book" (cfgd)
```

Configuring and Verifying GLBP

GLBP configuration mimics HSRP configuration to a great degree. In fact, if you took the configuration in Example 6-1, removed the **standby version 2** command (which applies only to HSRP), and replaced each **standby** with **glbp**, the result would be a completely valid GLBP configuration.

GLBP requires only a single interface subcommand on each router: the **glbp** *group* **ip** *virtual-ip* interface subcommand. The ideas behind this one command work just like HSRP as well: All routers use the same group number, and all routers configure the same virtual IP address.

Example 6-4 shows a GLBP configuration that would be typical if migrating from using HSRP, as shown in Example 6-1, to the equivalent GLBP configuration. Both routers use GLBP group 1, with virtual IP address 10.1.1.1, with the **glbp 1 ip 10.1.1.1** interface subcommand.

Example 6-4. GLBP Configuration on R1 and R2, Sharing IP Address 10.1.1.1

Click here to view code image

```
! First, the configuration on R1
R1# show running-config
! Lines omitted for brevity
interface GigabitEthernet0/0
ip address 10.1.1.9 255.255.255.0
glbp 1 ip 10.1.1.1
glbp 1 priority 110
glbp 1 name GLBP-group-for-book
```

```
! The following configuration, on R2, is identical except for
! the interface IP address, and the GLBP priority
R2# show running-config
! Lines omitted for brevity
interface GigabitEthernet0/0
ip address 10.1.1.129 255.255.255.0
glbp 1 ip 10.1.1.1
glbp 1 name HSRP-group-for-book
```

Once configured, the two routers negotiate as to which will be the AVG. As with HSRP, if both come up at the same time, R1 will win, with a priority set to 110 with the **glbp 1 priority 110** command versus R2's default priority of 100. However, if either router comes up before the other, that router goes ahead and takes on the AVG role.

Sifting through the GLBP **show** command output takes a little more work with HSRP, in particular because of the added detail in how GLBP works. First, consider the **show glbp brief** command on router R1, as shown in Example 6-5. (Note that many **show glbp** commands have the same options as equivalent HSRP **show standby** commands.)

Example 6-5. GLBP Status on R1 with show glbp brief

Click here to view code image

```
R1# show glbp brief
Interface Grp Fwd Pri State Address Active router Standby router
Gi0/0 1 - 110 Active 10.1.1.1 local 10.1.1.129
Gi0/0 1 1 - Listen 0007.b400.0101 10.1.1.129 -
Gi0/0 1 2 - Active 0007.b400.0102 local
```

Before looking at the right side of the output, first consider the context for a moment. This example lists a heading line and three rows of data. These rows data rows are identified by the Grp and Fwd headings, short for Group and Forwarder. With only one GLBP group configured, R1 lists lines only for group 1. More important, each row defines details about a different part of what GLBP does, as follows:

Fwd is -: This line refers to none of the forwarders, and instead describes the AVG.

Fwd is 1: This line describes GLBP forwarder (router) 1.

Fwd is 2: This line describes GLBP forwarder (router) 2.

The output usually lists the line about the AVG first, as noted with a dash in the Forwarder column. Now looking at the highlighted portions on the right of Example 6-5. This line will list the virtual IP address and identify the active AVG and the standby AVG. This particular command, from router R1, lists R1 itself ("local") as the active router. So, R1 is the current AVG.

Each of the next two lines lists status information about one of the forwarder roles; that is, a router that uses a virtual MAC address, receives frames sent to that address, and routes the packets encapsulated in those frames. To that end, the Address column lists MAC addresses, specifically the virtual MAC addresses used by GLBP, and not the interface MAC addresses.

Each forwarder row also identifies the router that currently uses the listed virtual MAC in the Active Router column. In Example 6-5, 0007.b400.0101 is used by the router with interface IP address 10.1.1.129 (which happens to be R2). 0007.b400.0102 is supported by the local router (the router on which the **show** command was issued), which is R1.

The brief output of the **show glbp brief** lists many details, but with some effort to learn how to sift through it all. For more perspective on the output, Example 6-6 lists this same **show glbp brief** command, this time on R2. Note that the Fwd column again identifies the first line of output as being about the AVG, with the next two lines about the two forwarders.

Example 6-6. GLBP Status on R2 with show standby brief

Click here to view code image

```
R1# show glbp brief
Interface Grp Fwd Pri State Address Active router Standby router
Gi0/0 1 - 100 Standby 10.1.1.1 10.1.1.9 local
Gi0/0 1 1 - Active 0007.b400.0101 local -
Gi0/0 1 2 - Listen 0007.b400.0102 10.1.1.9 -
```

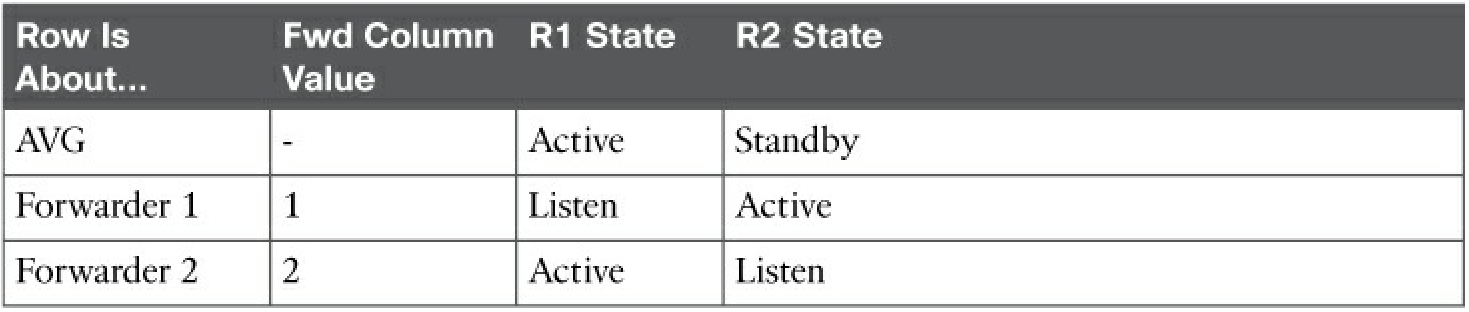
The State column in the output in Examples 6-5 and 6-6 can pull the GLBP concepts together. First, to define the meaning of the state values, the following short list defines the states expected for the first line of output, about the AVG, and then about each GLBP forwarder:

AVG: One router should be the active AVG, with the other acting as standby, ready to take over the AVG role if the AVG fails.

Each forwarder: One router should be active, while the other should be listening, ready to take over that virtual MAC address if that forwarder fails.

Table 6-3 collects the values of the State column from Example 6-5 and 6-6 for easier reference side by side. Note that, indeed, each line has either an active/standby pair (for the AVG) or an active/listen pair (for the forwarder function).

Table 6-3. Comparing Local State in show glbp brief **Commands**



Row Is About...	Fwd Column Value	R1 State	R2 State
AVG	-	Active	Standby
Forwarder 1	1	Listen	Active
Forwarder 2	2	Active	Listen

Finally, the **show glbp** command lists a more detailed view of the current GLBP status. Example 6-7 shows a sample from router R1. Note that the first half of the output has similar information compared to HSRP's **show standby** command, plus it lists the IP and MAC addresses of the routers in the GLBP group. Then, the end of the output lists a group of messages per GLBP forwarder.

Example 6-7. GLBP Status on R1 with show glbp

Click here to view code image

```
R1# show glbp
GigabitEthernet0/0 - Group 1
State is Active
2 state changes, last state change 00:20:59
Virtual IP address is 10.1.1.1
Hello time 3 sec, hold time 10 sec
Next hello sent in 2.112 secs
Redirect time 600 sec, forwarder timeout 14400 sec
Preemption disabled
Active is local
Standby is 10.1.1.129, priority 100 (expires in 8.256 sec)
Priority 110 (configured)
Weighting 100 (default 100), thresholds: lower 1, upper 100
Load balancing: round-robin
IP redundancy name is "GLBP-group-for-book"
Group members:
```

```
0200.0101.0101 (10.1.1.9) local
0200.0202.0202 (10.1.1.129)
There are 2 forwarders (1 active)
Forwarder 1
State is Listen
2 state changes, last state change 00:20:34
MAC address is 0007.b400.0101 (learnt)
Owner ID is 0200.0202.0202
Redirection enabled, 598.272 sec remaining (maximum 600 sec)
Time to live: 14398.272 sec (maximum 14400 sec)
Preemption enabled, min delay 30 sec
Active is 10.1.1.129 (primary), weighting 100 (expires in 8.352 sec)
Client selection count: 1
Forwarder 2
State is Active
1 state change, last state change 00:24:25
MAC address is 0007.b400.0102 (default)
Owner ID is 0200.0101.0101
Redirection enabled
Preemption enabled, min delay 30 sec
Active is local, weighting 100
Client selection count: 1
```

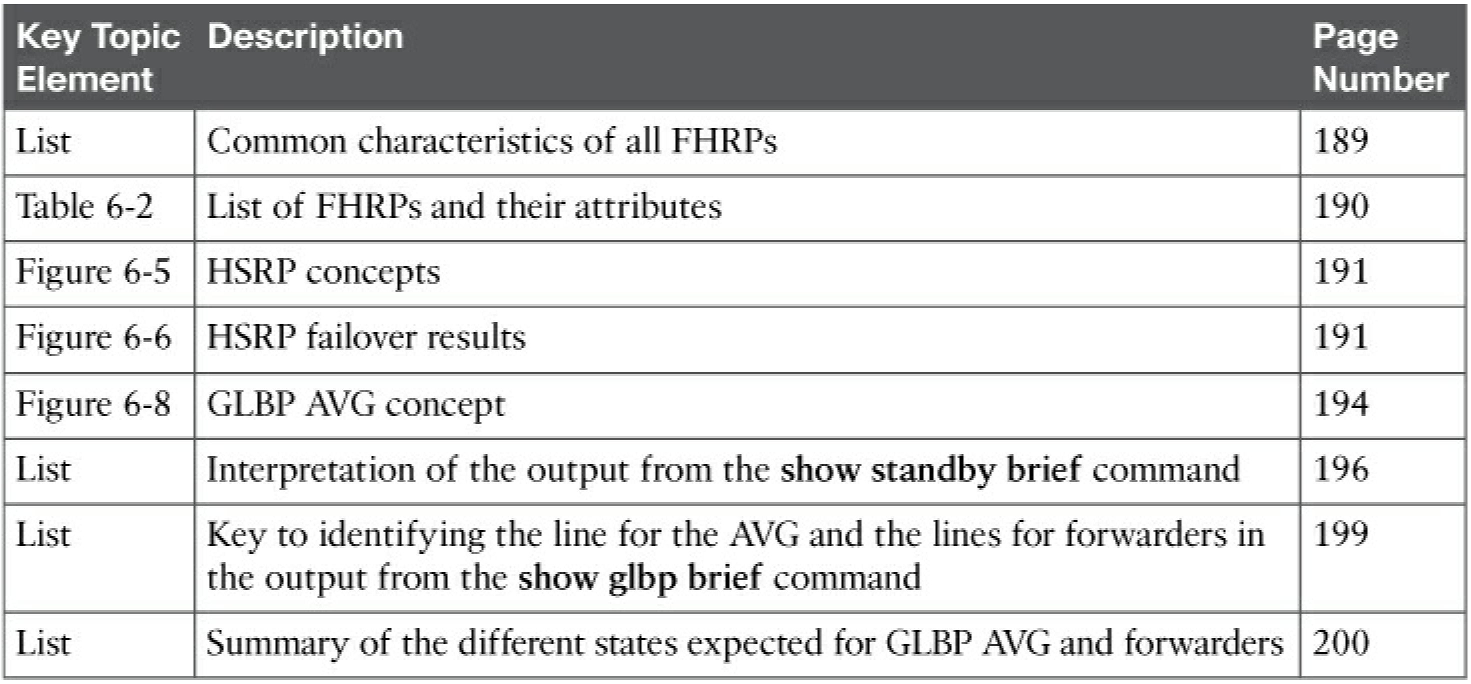
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 6-4 lists these key topics and where each is discussed.

Key Topic

Table 6-4. Key Topics for Chapter 6



Key Topic Element	Description	Page Number
List	Common characteristics of all FHRPs	189
Table 6-2	List of FHRPs and their attributes	190
Figure 6-5	HSRP concepts	191
Figure 6-6	HSRP failover results	191
Figure 6-8	GLBP AVG concept	194
List	Interpretation of the output from the **show standby brief** command	196
List	Key to identifying the line for the AVG and the lines for forwarders in the output from the **show glbp brief** command	199
List	Summary of the different states expected for GLBP AVG and forwarders	200

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix D, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix E, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22 directs you in how to use these terms for late-stage preparation for the exam.

single point of failure
First Hop Redundancy Protocol (FHRP)
Hot Standby Router Protocol (HSRP)
Virtual Router Redundancy Protocol (VRRP)
Gateway Load Balancing Protocol (GLBP)
virtual IP address
virtual MAC address
HSRP active
HSRP standby
GLBP active
GLBP standby
GLBP Forwarder
active virtual gateway

Command Reference to Check Your Memory

Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To check to see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table with a piece of paper, read the descriptions on the right side, and see whether you remember the command.

Table 6-5. Chapter 6 Configuration Command Reference

Command	Description
standby *group-number* **ip** *virtual-ip*	Interface subcommand that enables HSRP, defines a virtual IP address, and associates it with a particular HSRP group.
standby *group-number* **priority** *0...255*	Interface subcommand that configures a priority, influencing which router becomes the active HSRP router. The higher the number wins, with a default of 100. This command associates the setting with a particular HSRP group.
standby *group-number* **name** *descriptive-name*	Interface subcommand that defines a name and associates it with a particular GLBP group.
standby version 1 | 2	Interface subcommand that sets the HSRP version used for all groups on the interface.
glbp *group-number* **ip** *virtual-ip*	Interface subcommand that enables GLBP, defines a virtual IP address, and associates it with a particular GLBP group.
glbp *group-number* **priority 0..255**	Interface subcommand that configures a priority, influencing which router becomes the active HSRP router. The higher the number wins, with a default of 100. This command associates the setting with a particular HSRP group.
glbp *group-number* **name** *descriptive-name*	Interface subcommand that defines a name and associates it with a particular HSRP group.

Table 6-6. Chapter 6 EXEC Command Reference

Command	Description
show standby	Lists details about HSRP status, including the virtual IP address, currently active and standby routers, virtual MAC addresses, and counters.
show standby brief	Lists a single line of status information for each HSRP group, with the currently active and standby routers and virtual IP address.
show glbp	Lists details about GLBP status, including the virtual IP address, the current AVG, each forwarder (router), and which routers currently support each virtual MAC address.
show glbp brief	For each GLBP group, it lists one initial line of status information about the AVG, with another line for each forwarder (router) in the GLBP group. The data identifies the AVG, the standby AVG, the virtual MAC addresses, and which routers are currently active and listening for each virtual MAC address.

Chapter 7. Virtual Private Networks

This chapter covers the following exam topics:

WAN Technologies

Identify different WAN technologies

VPN

A company with 1 main site and 10 remote sites could lease several different types of WAN services to connect the sites: leased lines, Frame Relay, or more likely today, Multiprotocol Label Switching (MPLS). However, another option for connecting remote sites is to simply connect each site to the Internet using some high-speed Internet access technology like cable or digital subscriber line (DSL). Then the sites can send IP packets to each other over the Internet, using the Internet as a WAN.

Unfortunately, the Internet is not nearly as secure as leased lines and other WAN options. For example, for an attacker to steal a copy of data frames passing over a leased line, the attacker would have to physically tap into the cable, often inside a secure building, under the street, or at the telco central office (CO); all of these actions can result in a jail sentence. With the Internet, an attacker can find less-intrusive ways to get copies of packets, without even having to leave his home computer, and with a much smaller risk of getting carted off to jail.

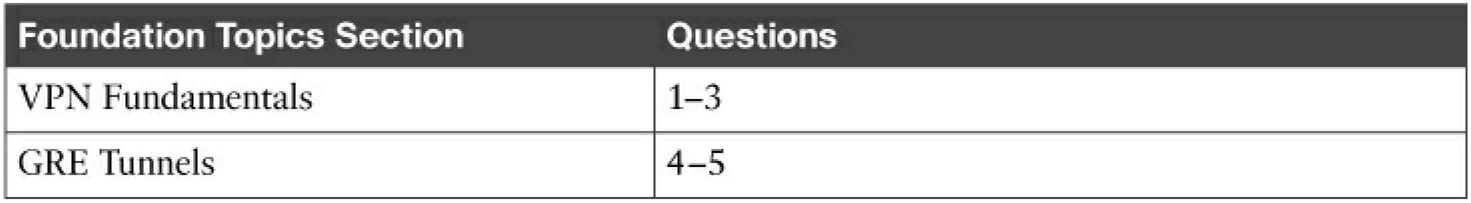
Virtual private networks (VPN) solve the security problems associated with using the public Internet as a private WAN service. This chapter explains the concepts and terminology related to VPNs.

This chapter has two main sections. The first section introduces the basic concept of a VPN and discusses some details of two main types: IP Security (IPsec) and Secure Sockets Layer (SSL). The second section looks at one of the fundamental building blocks of VPNs, the concept of a tunnel between two routers, as created by an IP network.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 7-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
VPN Fundamentals	1–3
GRE Tunnels	4–5

1. Which of the following terms refers to a VPN that uses the Internet to connect the sites of a single company rather than using leased lines or Frame Relay?
   - **a.** Intranet VPN
   - **b.** Extranet VPN
   - **c.** Remote-access VPN
   - **d.** Enterprise VPN
2. Which of the following are not considered to be security functions provided by a site-to-site VPN?
   - **a.** Message integrity checks
   - **b.** Privacy (encryption)
   - **c.** Antivirus
   - **d.** Authentication
3. Which of the following is not a function of IPsec?
   - **a.** Authentication
   - **b.** Intrusion prevention
   - **c.** Message integrity checks
   - **d.** Anti-replay
4. Router A configures a tunnel using the **tunnel destination 5.5.5.5** command. Router B serves as the router on the other end of the tunnel. Which of the following answers is accurate about the configuration on router B?
   - **a.** Router B will list 5.5.5.5 in an **ip address** subcommand under a tunnel interface.
   - **b.** Router B will list 5.5.5.5 in an **ip address** subcommand under an interface other than a tunnel.
   - **c.** Router A must use an IP address in the same subnet as 5.5.5.5 on its **tunnel source** command.
5. Routers A and B configure and use a GRE tunnel, using OSPFv2 to learn IPv4 routes over that tunnel. Router A has a LAN IP address/mask of 172.16.1.0/24 and a tunnel source of 8.8.8.8. Router B has a LAN IP address/mask of 172.16.2.0/24 and a tunnel source of 9.9.9.9. Which of the following routes will router A likely learn with OSPFv2 so that the route lists the tunnel interface as the outgoing interface?

a. A route for 172.16.1.0/24
b. A route for 172.16.2.0/24
c. A route for 8.8.8.8
d. A route for 9.9.9.9

Answers to the “Do I Know This Already?” quiz:

1 A **2** C **3** B **4** B **5** B

Foundation Topics

VPN Fundamentals

Leased lines have some wonderful security features. The router on one end knows with confidence the identity of the device on the other end of the link. The receiving router also has good reason to believe that no attackers saw the data in transit, or even changed the data to cause some harm.

VPNs try to provide the same secure features as a leased line while sending data over a network that is open to other parties. In fact, the data often crosses the Internet. Even when sending data over public networks like the Internet, VPNs can provide the following:

Key Topic

- **Confidentiality (Privacy):** Preventing anyone in the middle of the Internet (man in the middle) from being able to read the data
- **Authentication:** Verifying that the sender of the VPN packet is a legitimate device and not a device used by an attacker
- **Data integrity:** Verifying that the packet was not changed as the packet transited the Internet
- **Anti-replay:** Preventing a man in the middle from copying and later replying the packets sent by a legitimate user, for the purpose of appearing to be a legitimate user

To accomplish these goals, two devices near the edge of the Internet create a VPN, sometimes called a *VPN tunnel*. These devices add headers to the original packet, with these headers including fields that allow the VPN devices to perform all the functions. The VPN devices also encrypt the original IP packet, meaning that the original packet’s contents are undecipherable to anyone who happens to see a copy of the packet as it traverses the Internet.

Figure 7-1 shows the general idea of what typically occurs with a VPN tunnel. The figure shows a VPN created between a branch office router and a Cisco Adaptive Security Appliance (ASA). In this case, the VPN is called a *site-to-site VPN* because it connects two sites of a company. This VPN is also called a site-to-site *intranet* VPN because it connects sites that belong inside a single company.

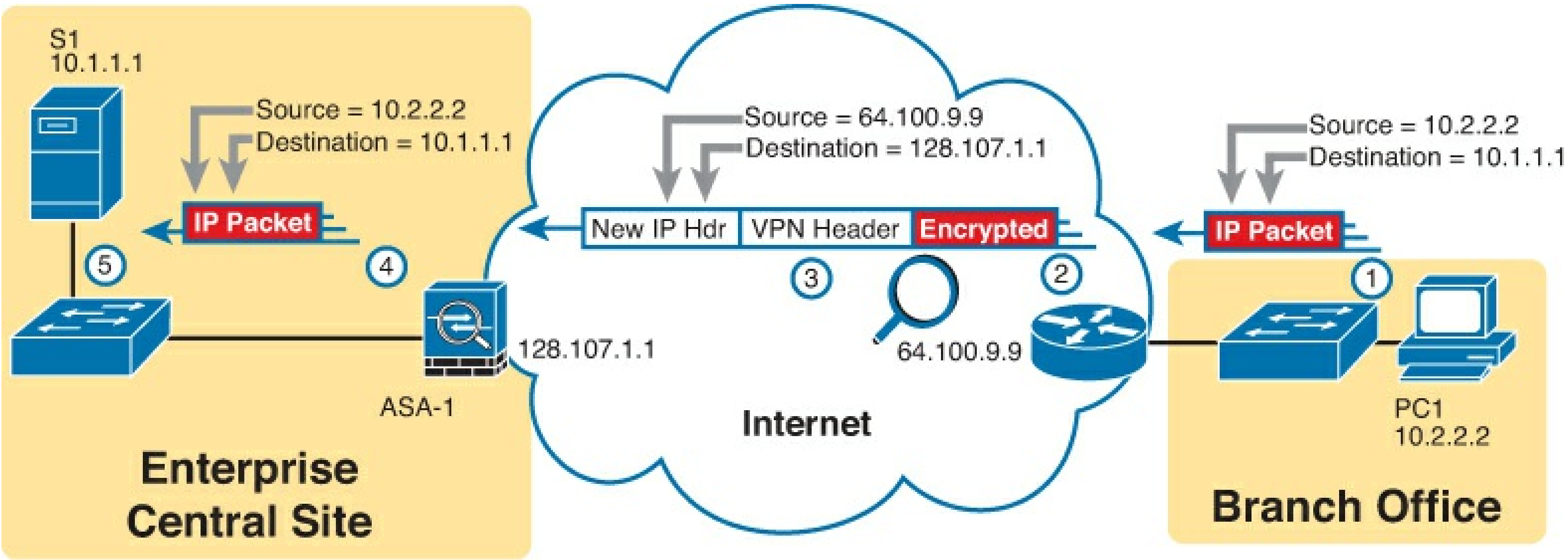

S1
10.1.1.1
Source = 10.2.2.2
Destination = 10.1.1.1
IP Packet
5
4
ASA-1
128.107.1.1
Enterprise Central Site
Source = 64.100.9.9
Destination = 128.107.1.1
New IP Hdr
VPN Header
Encrypted
3
2
64.100.9.9
Internet
Source = 10.2.2.2
Destination = 10.1.1.1
IP Packet
1
PC1
10.2.2.2
Branch Office

Figure 7-1. VPN Tunnel Concepts for a Site-to-Site Intranet VPN

The figure shows the following steps, which explain the overall flow in the figure:

1. Host PC1 (10.2.2.2) on the right sends a packet to the web server (10.1.1.1), just as it would without a VPN.
2. The router encrypts the packet, adds some VPN headers, adds another IP header (with public IP addresses), and forwards the packet.
3. A man in the middle copies the packet, but cannot change the packet without being noticed, and cannot read the contents of the original packet.
4. ASA-1 receives the packet, confirms the authenticity of the sender, confirms that the packet has not been changed, and then decrypts the original packet.
5. Server S1 receives the unencrypted packet.

The benefits of using an Internet-based VPN as shown in Figure 7-1 are many. The cost of a high-speed Internet connection is usually much less than that of many modern WAN options. The Internet is seemingly everywhere, making this kind of solution available worldwide. And by using VPN technology and protocols, the communications are secure.

> **Note**
>
> The term *tunnel* generically refers to any protocol's packet that is sent by encapsulating the packet inside another packet. The term *VPN tunnel* implies that the encapsulated packet has been encrypted, whereas the term *tunnel* does not imply whether the packet has been encrypted.

VPNs can be built with a variety of devices and for a variety of purposes. Figure 7-2 shows an example of three of the primary reasons for building an Internet-based VPN today.

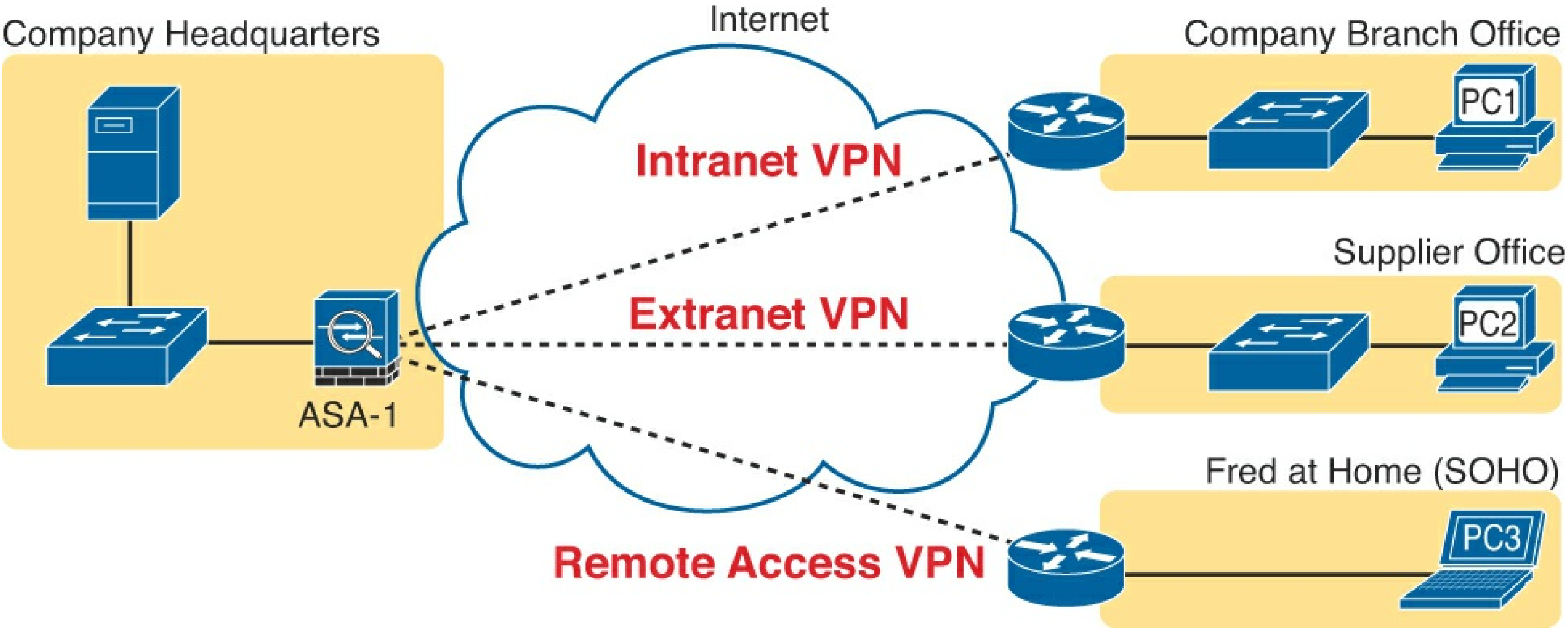
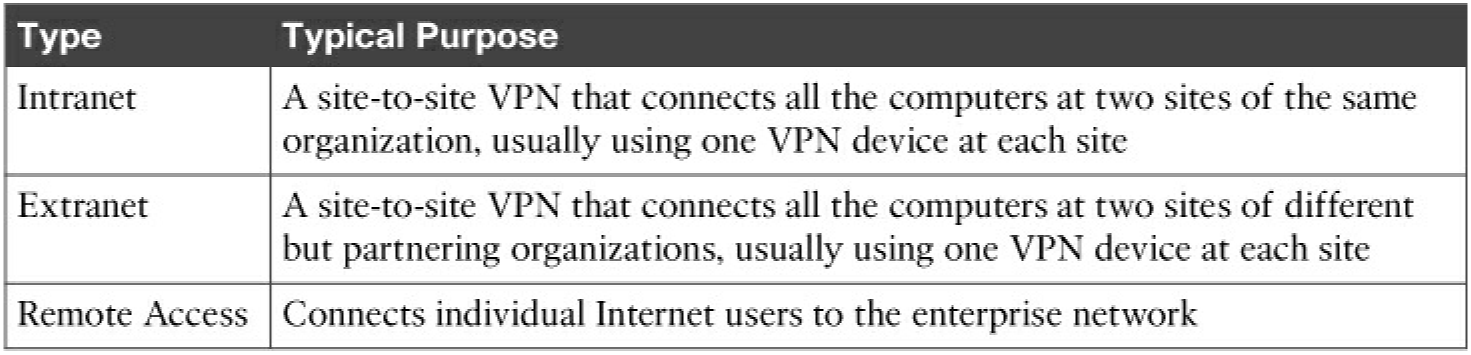

Company Headquarters
Internet
Company Branch Office
Intranet VPN
PC1
Supplier Office
Extranet VPN
PC2
ASA-1
Fred at Home (SOHO)
PC3
Remote Access VPN

Figure 7-2. Intranet, Extranet, and Access VPNs

In the top part of the figure, the central site and a remote branch office of a fictitious company are connected with an *intranet VPN*. The middle of the figure shows the Company connecting to a supplier, making that VPN an *extranet VPN*. Finally, when Fred brings his laptop home at the end of the day and connects to the Internet, the secure VPN connection from the laptop back into the company network is called a *remote-access VPN*, or simply an *access VPN*. In this case, the laptop itself is the end of the VPN tunnel, rather than the Internet access router. Table 7-2 summarizes the key points about these three types of

VPNs.

Table 7-2. Types of VPNs



Type	Typical Purpose
Intranet	A site-to-site VPN that connects all the computers at two sites of the same organization, usually using one VPN device at each site
Extranet	A site-to-site VPN that connects all the computers at two sites of different but partnering organizations, usually using one VPN device at each site
Remote Access	Connects individual Internet users to the enterprise network

To build a VPN, one device at each site needs to have hardware/software that understands a chosen set of VPN security standards and protocols. The devices include the following:

- **Routers:** In addition to packet forwarding, the router can provide VPN functions. The router can have specialized add-on cards that help the router perform the encryption more quickly.
- **Adaptive Security Appliances (ASA):** The Cisco leading security appliance that can be configured for many security functions, including acting as a VPN concentrator, supporting large numbers of VPN tunnels.
- **VPN client:** For remote-access VPNs, the PC might need to do the VPN functions; the laptop needs software to do those functions, with that software being called a *VPN client*.

Finally, when comparing VPNs to other WAN technologies, VPNs have several advantages. For instance, consider a company with 1000 small retail locations. The company could create a private WAN using leased lines, or Frame Relay, Ethernet WAN, Multiprotocol Label Switching (MPLS), and so on. However, each branch could instead have an Internet connection and use VPN technology, usually saving money over the other WAN options. Here are some of the benefits:

Cost: Internet VPN solutions can be cheaper than alternative private WAN options.

Security: Internet VPN solutions can be as secure as private WAN connections.

Scalability: Internet VPN solutions scale to many sites at a reasonable cost. Each site connects via any Internet connection, with most business locations having multiple competitive options to choose from for Internet access.

Next, the text examines the use of a set of protocols called *IPsec* to create VPNs, followed by a brief description of SSL VPNs.

IPsec VPNs

IPsec is an architecture or framework for security services for IP networks. The name itself is not an acronym, but rather a name derived from the title of the RFC that defines it (RFC 4301, *Security Architecture for the Internet Protocol*), more generally called IP Security, or IPsec.

IPsec defines how two devices, both connected to the Internet, can achieve the main goals of a VPN as listed at the beginning of this chapter: confidentiality, authentication, data integrity, and anti-replay. IPsec does not define just one way to implement a VPN, instead allowing several different protocol options for each VPN feature. One of IPsec's strengths is that its role as an architecture allows it to be added to and changed over time as improvements to individual security functions are made.

This chapter does not go through the details of each part of IPsec, but to give you some general idea of some of IPsec's work, this section shows how two IPsec endpoints encrypt data and add IPsec VPN headers to the encrypted data.

The idea of IPsec encryption might sound intimidating, but if you ignore the math—and thankfully, you can—IPsec encryption is not too difficult to understand. IPsec encryption uses a pair of encryption algorithms, which are essentially math formulas, to meet a couple of requirements. First, the two math formulas are a matched set:

- One to hide (encrypt) the data
- Another to re-create (decrypt) the original data based on the encrypted data

Besides those somewhat obvious functions, the two math formulas were chosen so that if you intercept the encrypted text but do not have the secret password (called an *encryption key*), decrypting that one packet would be difficult. In addition, the formulas are also chosen so that if an attacker did happen to decrypt one packet, that information would not give the attacker any advantages in decrypting the other packets.

The process for encrypting data for an IPsec VPN works generally as shown in Figure 7-3. Note that the *encryption key* is also known as the *session key*, *shared key*, or *shared session* key.

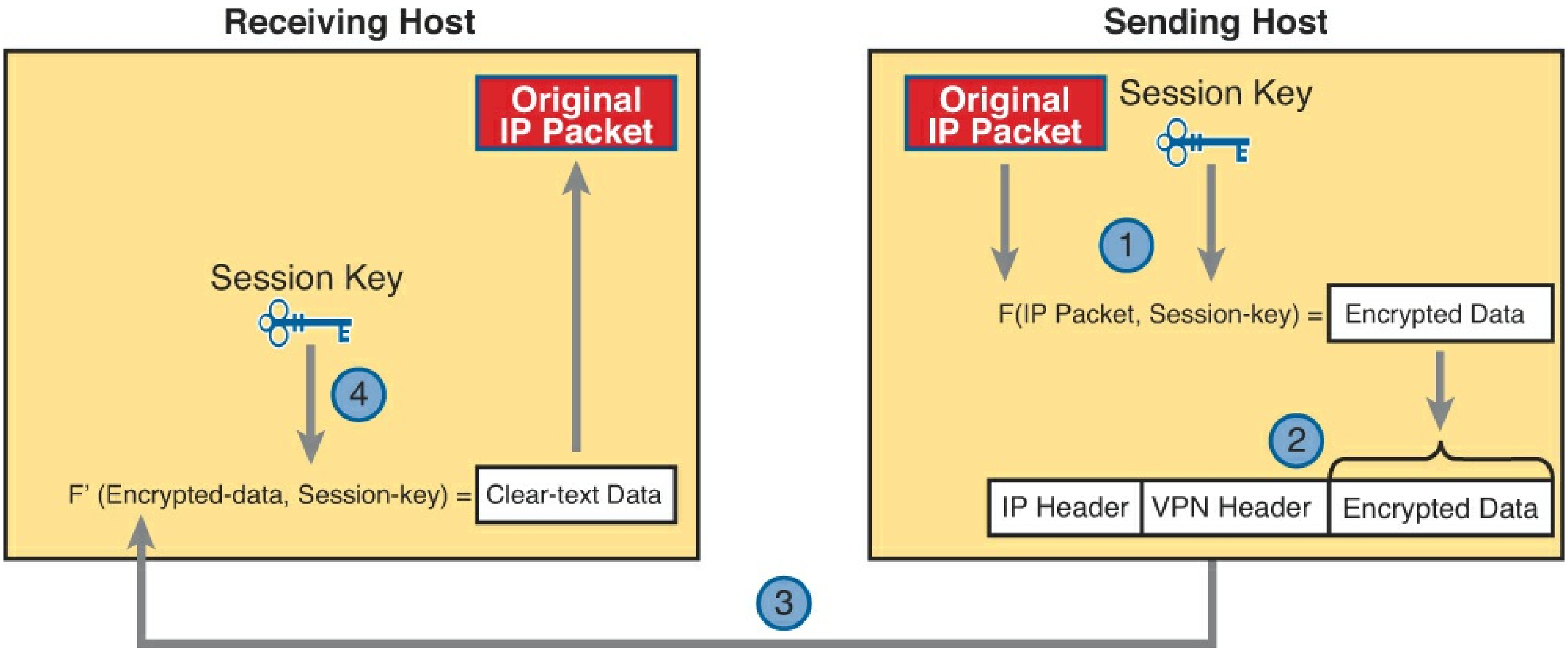


Figure 7-3. Basic IPsec Encryption Process

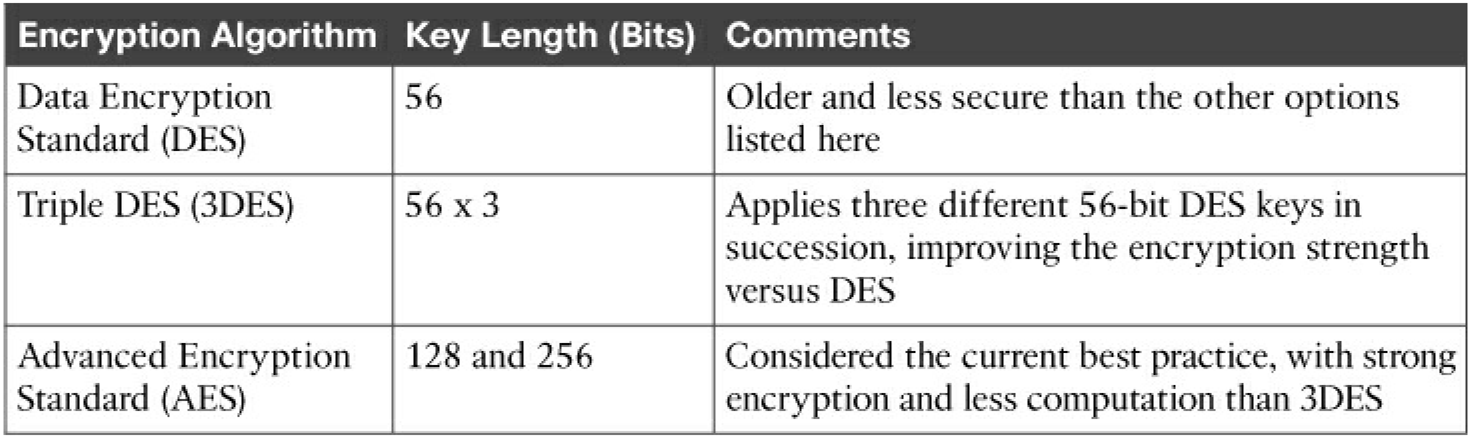
The four steps highlighted in the figure are as follows:

1. The sending VPN device (like the remote office router in Figure 7-1) feeds the orignal packet and the session key into the encryption formula, calculating the encrypted data.
2. The sending device encapsulates the encrypted data into a packet, which includes the new IP header and VPN header.
3. The sending device sends this new packet to the destination VPN device (ASA-1 back in Figure 7-1).
4. The receiving VPN device runs the corresponding decryption formula, using the encrypted data and session key—the same key value as was used on the sending VPN device—to decrypt the data.

Next, to give you some perspective about the flexibility of IPsec, IPsec has been changed over time to support newer and better encryption standards. For instance, newer standards have new algorithms, plus they often use longer keys. These changes make it more difficult for attackers to decrypt any data copied as it passes over the Internet. Table 7-3 summarizes several of these options and the lengths of the keys.

Key Topic

Table 7-3. Comparing VPN Encryption Algorithms



Encryption Algorithm	Key Length (Bits)	Comments
Data Encryption Standard (DES)	56	Older and less secure than the other options listed here
Triple DES (3DES)	56 x 3	Applies three different 56-bit DES keys in succession, improving the encryption strength versus DES
Advanced Encryption Standard (AES)	128 and 256	Considered the current best practice, with strong encryption and less computation than 3DES

SSL VPNs

The Secure Socket Layer (SSL) protocol serves as an alternative VPN technology to IPsec. In particular, today's web browsers support SSL as a way to dynamically create a secure connection from the web browser to a web server, supporting safe online access to financial transactions. This brief topic explains a few details about how you can use SSL to create remote-access VPNs.

Web browsers use HTTP as the protocol with which to connect to web servers. However, when the communications with the web server need to be secure, the browser switches to use SSL. SSL uses well-known port 443, encrypting data sent between the browser and the server and authenticating the user. Then, the HTTP messages flow over the SSL VPN connection.

The built-in SSL functions of a web browser create one secure web browsing session, but this same SSL technology can be used create a remote access VPN using a Cisco VPN client. The Cisco AnyConnect VPN client is software that sits on a user's PC and uses SSL to create one end of a VPN remote-access tunnel. As a result, all the packets sent to the other end of the tunnel are encrypted, not just those sent over a single HTTP connection in a web browser.

Finally, note that many types of devices can sit on the server side of an SSL connection as well. The web server can be the endpoint of an SSL connection from a web browser, but often, to improve server performance, the SSL tunnel on the server side terminates on specialized devices like the Cisco ASA.

Figure 7-4 combines all the SSL concepts into one example with two SSL tunnels. One SSL VPN tunnel connects a web browser at host A to the ASA on the right, supporting a single web browsing session. Host B uses the Cisco VPN client, so all packets from host B to the site on the right will be secured over the SSL connection.

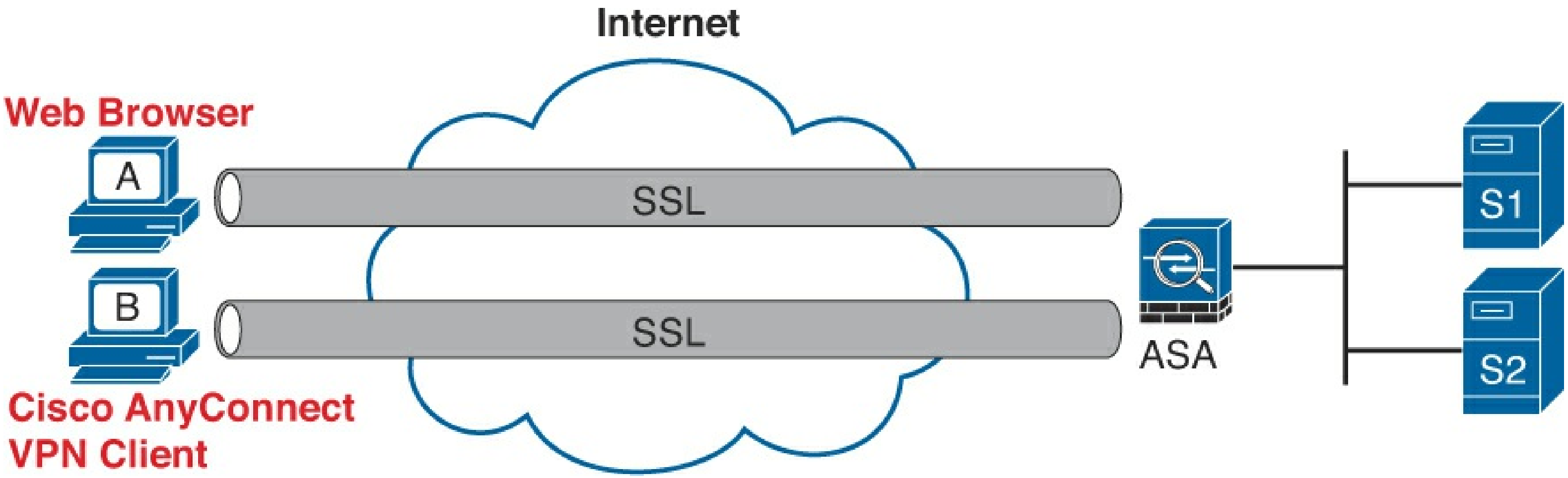


Figure 7-4. SSL VPN Options

Now that you have read about a couple of VPN options, the next section examines how to create a tunnel with configuration in a router.

GRE Tunnels

The device on the endpoint of a VPN takes a normal unencrypted packet and performs several functions before forwarding that packet. One of those functions is to encrypt the packet, and another is to encapsulate the packet in a new IP header. The new IP header uses addresses that allow the routers in the unsecured network between the two VPN tunnel endpoints to forward the VPN IP packet. The original IP packet, including the original IP header, is encrypted and unreadable.

This second major section of this chapter takes a little different approach to configuring a VPN tunnel, by looking at only the tunneling part of the work and ignoring the encryption function. Specifically, this section looks at the concepts and configuration of how routers create a tunnel, encapsulating the original IP packet inside another IP packet. The goal is to give you some general ideas about how tunneling works, while leaving the detailed security configuration to other certifications like CCNA Security.

GRE Tunnel Concepts

This chapter looks at one type of IP tunnel: generic routing encapsulation (GRE). GRE, defined in RFC 2784, defines an additional header, along with the new IP header, that encapsulates the original packet. Two routers work together, with matching configuration settings, to create a GRE IP tunnel. Then, IPsec configuration can be added to encrypt the traffic.

The discussion of GRE tunnels looks at the concepts from several perspectives. The first section shows how packets can be routed over a GRE tunnel, much like using a serial link inside a secured enterprise network. The rest of this topic then explains how GRE does its work.

Routing over GRE Tunnels

A GRE tunnel exists between two routers, with the tunnel working very much like a serial link with regard to packet forwarding. So, before discussing GRE tunnels, this section first reviews some familiar facts about routers and serial links, using Figure 7-5 as an example.

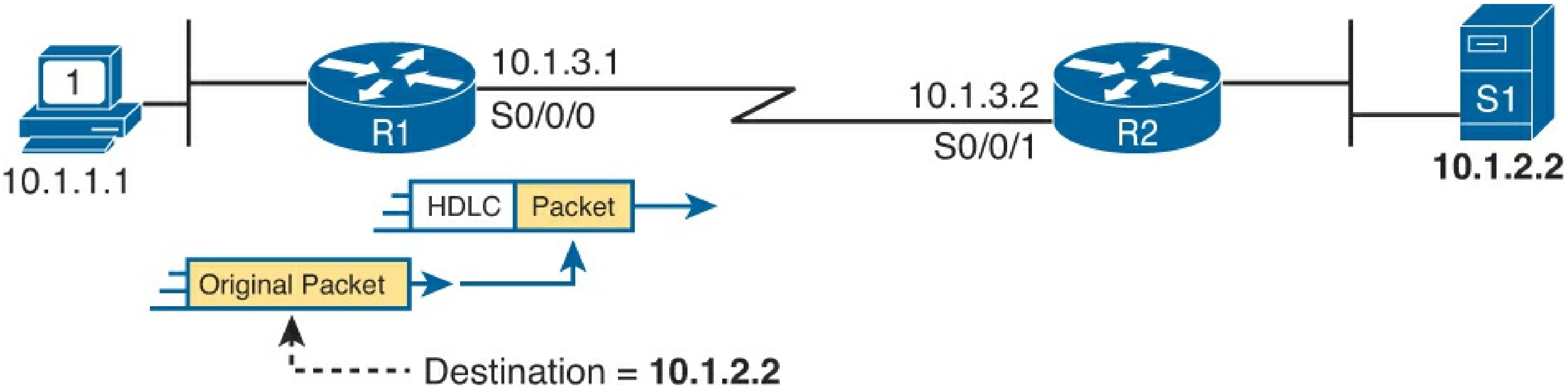


Figure 7-5. Routing an IP Packet over a Serial Link

The small network in Figure 7-5 looks like a part of many enterprise networks. It uses private IP addresses (network 10.0.0.0).

It has an IP address on each router interface, including on each serial interface. The IP addresses on the serial interfaces (10.1.3.1 and 10.1.3.2, respectively) are in the same subnet. And when PC1 sends a packet to destination IP address 10.1.2.2, R1 will encapsulate the packet in the data link protocol used on the link, like the default High-Level Data Link Control (HDLC) encapsulation shown in the figure.

Also, note that all the parts of this small enterprise network exist in secure spaces. This network has no need to encrypt data using a VPN.

GRE creates a concept that works just like the serial link in Figure 7-5, at least with regard to IP routing. Instead of a serial link with serial interfaces, the routers use virtual interfaces called *tunnel interfaces*. The two routers have IP addresses on their tunnel interfaces in the same subnet. Figure 7-6 shows an example where the serial link has been replaced with these virtual tunnel interfaces.

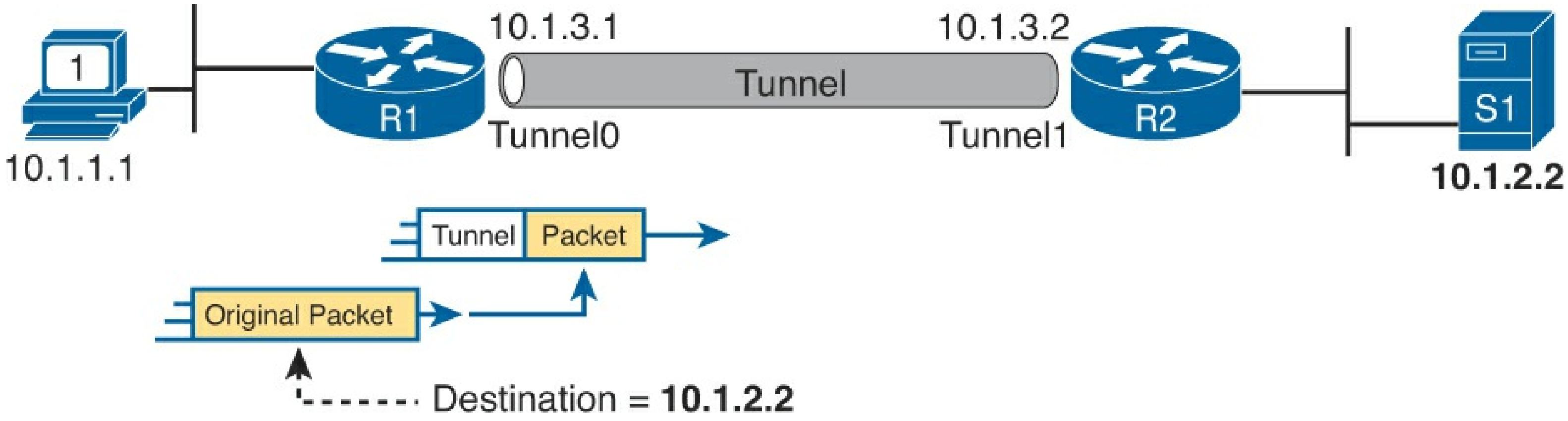

10.1.3.1
10.1.3.2
1
R1
Tunnel
R2
S1
Tunnel0
Tunnel1
10.1.1.1
10.1.2.2
Tunnel
Packet
Original Packet
Destination = 10.1.2.2

Figure 7-6. Replacing the Serial Link with an IP Tunnel

Sticking with the big ideas about IP routing for now, the tunnel looks like just another link in the secure part of the network. The tunnel IP addresses are from the secure enterprise network. The routers encapsulate the original packet inside a tunnel header, which takes the place of the serial link's HDLC header. And the routers will even have routes that list the tunnel interfaces (Tunnel0 and Tunnel1 in this case) as the outgoing interfaces.

To make use of the GRE tunnel, the routers treat it like any other link with a point-to-point topology. The routers have IPv4 addresses in the same subnet. The routers using a routing protocol become neighbors and exchange routes over the tunnel. And the routes learned over the tunnel list the tunnel interface as the outgoing interface, with the neighboring router's tunnel interface IP address as the next-hop router. Figure 7-7 shows an example, with the routes learned by each router listed at the bottom.

Key Topic

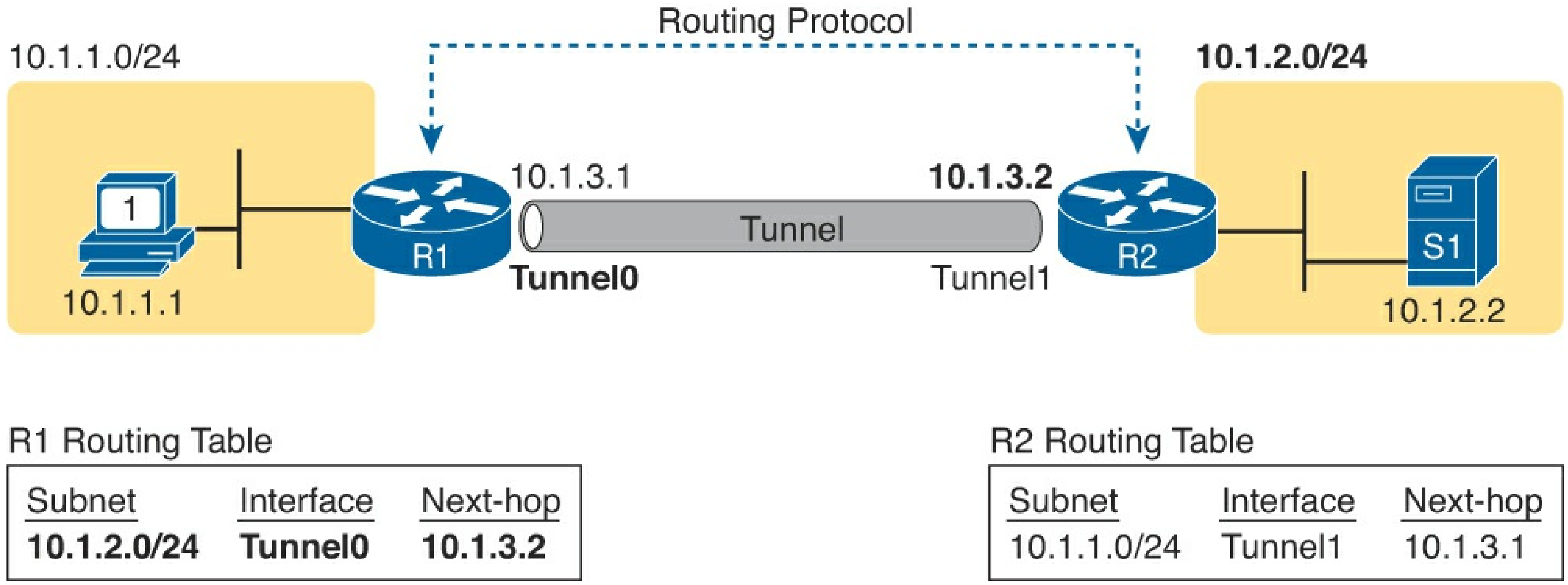

Routing Protocol
10.1.1.0/24
10.1.2.0/24
1
10.1.1.1
R1
10.1.3.1
Tunnel
10.1.3.2
R2
S1
10.1.2.2
Tunnel0
Tunnel1
R1 Routing Table
Subnet
Interface
Next-hop
10.1.2.0/24
Tunnel0
10.1.3.2
R2 Routing Table
Subnet
Interface
Next-hop
10.1.1.0/24
Tunnel1
10.1.3.1

Figure 7-7. Tunnel Routers Learning Private Routes over the IP Tunnel

Take a moment and look closely at the route for subnet 10.1.2.0/24, on the right side of the figure. R2 will have a connected route to that subnet. R1 and R2 will use some routing protocol (for instance, OSPF) to exchange routing information. R1 will add a new route for subnet 10.1.2.0/24, and that route will list R1's own tunnel interface, Tunnel0, as the outgoing interface. That route lists R2's tunnel interface IP address, 10.1.3.2, as the next hop router, as shown in R1's IP routing table on the bottom-left part of the figure.

All these concepts show how the GRE tunnel acts like just one more link in the secure part of an internetwork. The next few pages look at how GRE tunnels forward these packets over an unsecure network between the two routers.

GRE Tunnels over the Unsecured Network

The last few figures may have a tunnel between two routers, one that looks like a pipe, but those diagrams do not tell us much about the physical network behind the tunnel. The tunnel can exist over any IP network. The tunnel is created using an IP network to forward the original packets, so any IP network between routers R1 and R2 would allow the tunnel to exist.

Often, site-to-site VPNs, like the one shown in Figure 7-6, use an unsecured network like the Internet as the IP network. The whole idea ties back to economics. The monthly cost of high-speed Internet access at each site is often less than paying for other WAN services. But no matter what type of Internet connection exists, the routers on the tunnel can use the Internet as a way to forward the packets between the two tunnel routers, as shown in Figure 7-8.

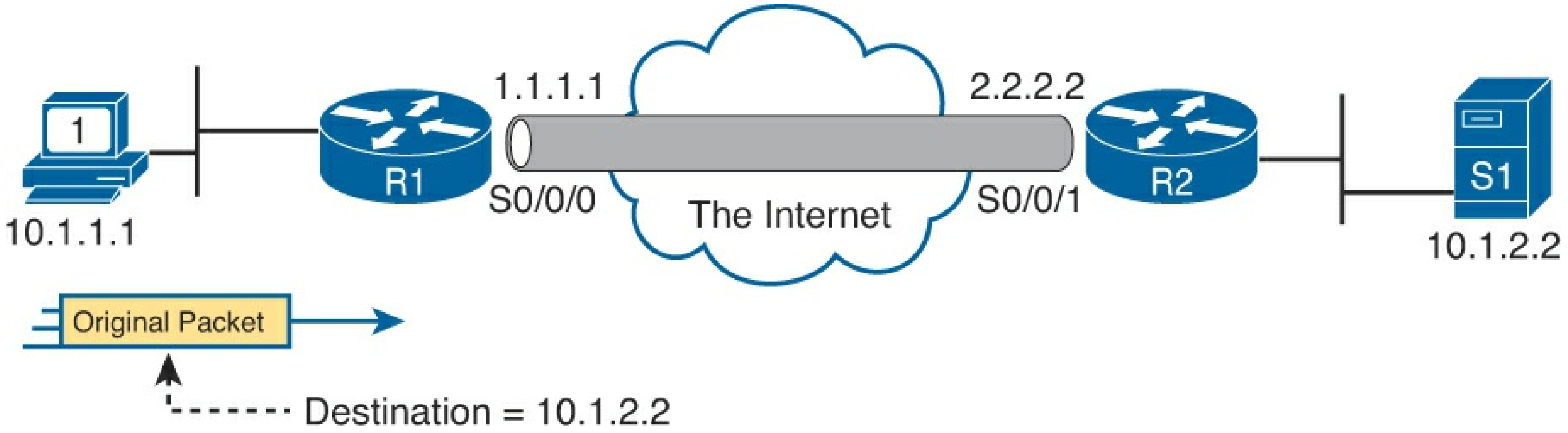


Figure 7-8. Sending the Tunnel over the Internet

The routers on the ends of the GRE tunnel create the tunnel by agreeing to send each other packets over the unsecure network between the two. Figure 7-8 shows many of the details that the engineer needs to know about the two routers before configuring the GRE tunnel on both ends. The figure shows the interfaces R1 and R2 each use to connect to the Internet. And it shows the IP addresses each router uses on their Internet connections, in this case 1.1.1.1 and 2.2.2.2, just to use more memorable numbers.

The router configuration uses virtual interfaces called *tunnel interfaces*. These interfaces do not exist until the engineer creates the tunnel with the **interface tunnel** command. For instance, the command **interface tunnel 0** creates a tunnel interface numbered as 0. To create a tunnel, both routers create a tunnel interface and use IP addresses as if the tunnel were a point-to-point link.

Figure 7-9 shows a conceptual diagram of a packet coming into router R1 from PC1, one that needs to be forwarded over the GRE tunnel to server S1 (10.1.2.2). When the router uses its IP routing logic from the secured part of the network, as shown in Figure 7-6, R1 wants to send the packet over the tunnel. Figure 7-9 shows the encapsulation done by R1.

Key Topic

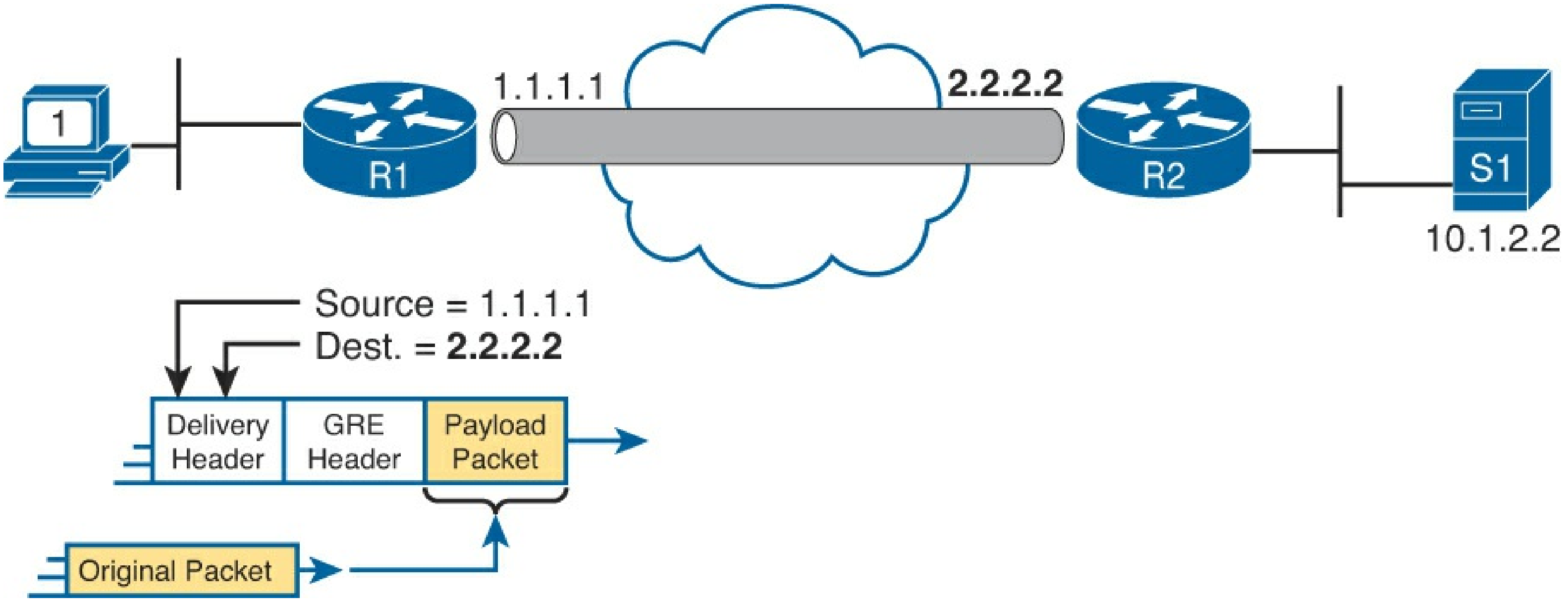


Figure 7-9. Encapsulating the Original IP Packet in a GRE-Formatted Packet

Note

If the two routers creating this tunnel also configured the IPsec encryption part of the tunnel, before encapsulating the original packet as shown in Figure 7-8, the sending router would first encrypt the packet.

GRE specifies the use of two headers to create the tunnel. GRE defines its own header, used to manage the tunnel itself. GRE also defines the use of a complete 20-byte IP header, called the *delivery header*. This header will use IP addresses from the unsecure network. In this case, the delivery IP header will list R1's 1.1.1.1 Internet IP address as the source and R2's 2.2.2.2 Internet IP address as the destination.

While this packet passes through the Internet, the routers in the Internet use this outer GRE delivery IP header to route the packet. The fact that this packet happens to hold another entire IP packet inside does not matter to the IP forwarding process in those routers; they just forward the IP packet based on the 2.2.2.2 destination IP address. Figure 7-10 shows the concept; note that this packet may be routed by many routers in the Internet before arriving at R2.

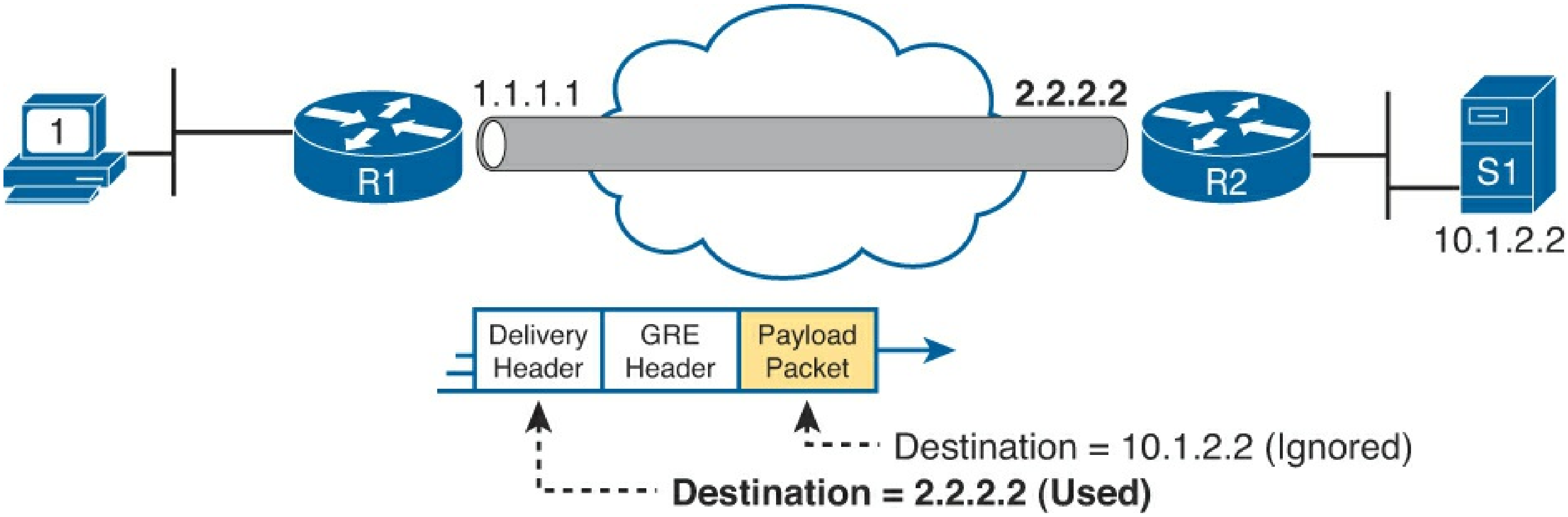


Figure 7-10. Internet Routers Forwarding GRE IP Packet Based on Public IP Addresses

When the GRE packet in Figure 7-10 finally arrives on the right side of the Internet, at R2, R2 needs to extract the original IP packet. With physical links, R2 would normally simply remove the old incoming data link header. With a GRE-encapsulated packet, the receiving router (R2) also needs to remove the delivery header and the GRE header, leaving the original packet, as shown in Figure 7-11.

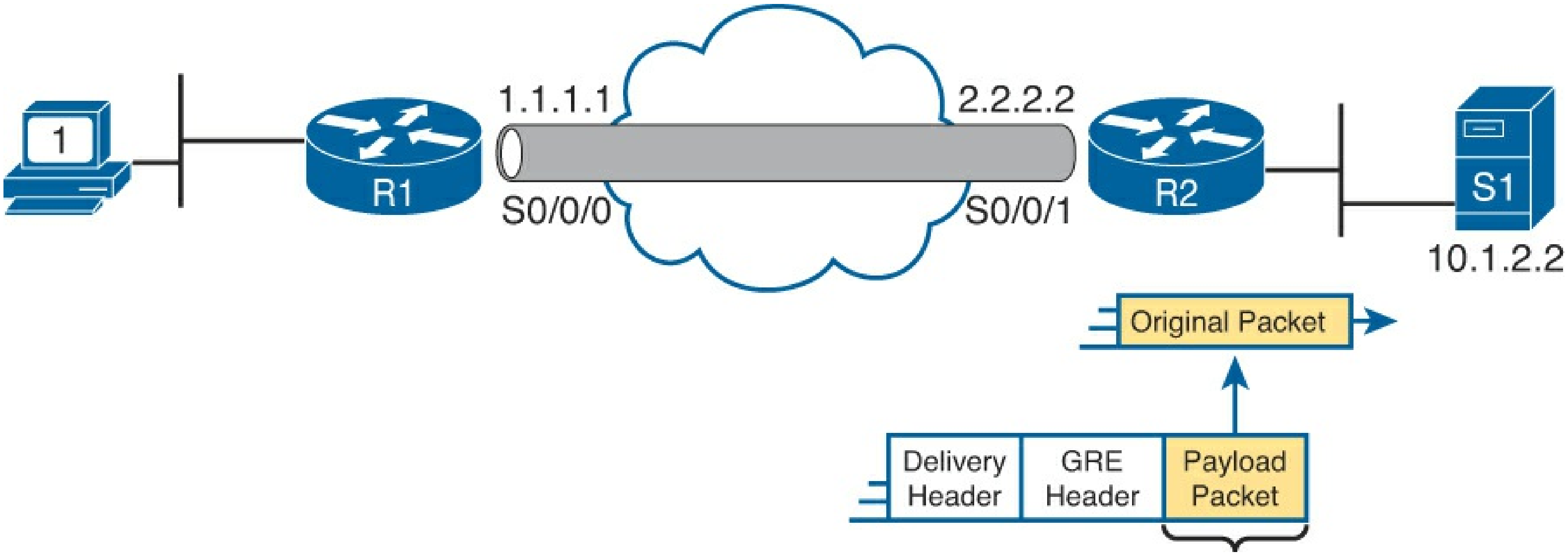


Figure 7-11. Internet Routers Forwarding GRE IP Packet Based on Public IP Addresses

Note

If the routers also configured the IPsec encryption part of the tunnel, just after the steps shown in Figure 7-11, the receiving router would then decrypt the original packet.

Configuring GRE Tunnels

Configuring GRE tunnels requires only a few commands. The challenge with GRE configuration comes in organizing the configuration parameters. The configuration requires a tunnel interface, with IP addresses from the secured part of the network configured with the **ip address** interface command. It also requires that the two routers declare both their own IP address (source) and the other router's IP address (destination), used in the unsecure part of the network. Figure 7-12 shows the organization of the various configuration parameters.

Key Topic

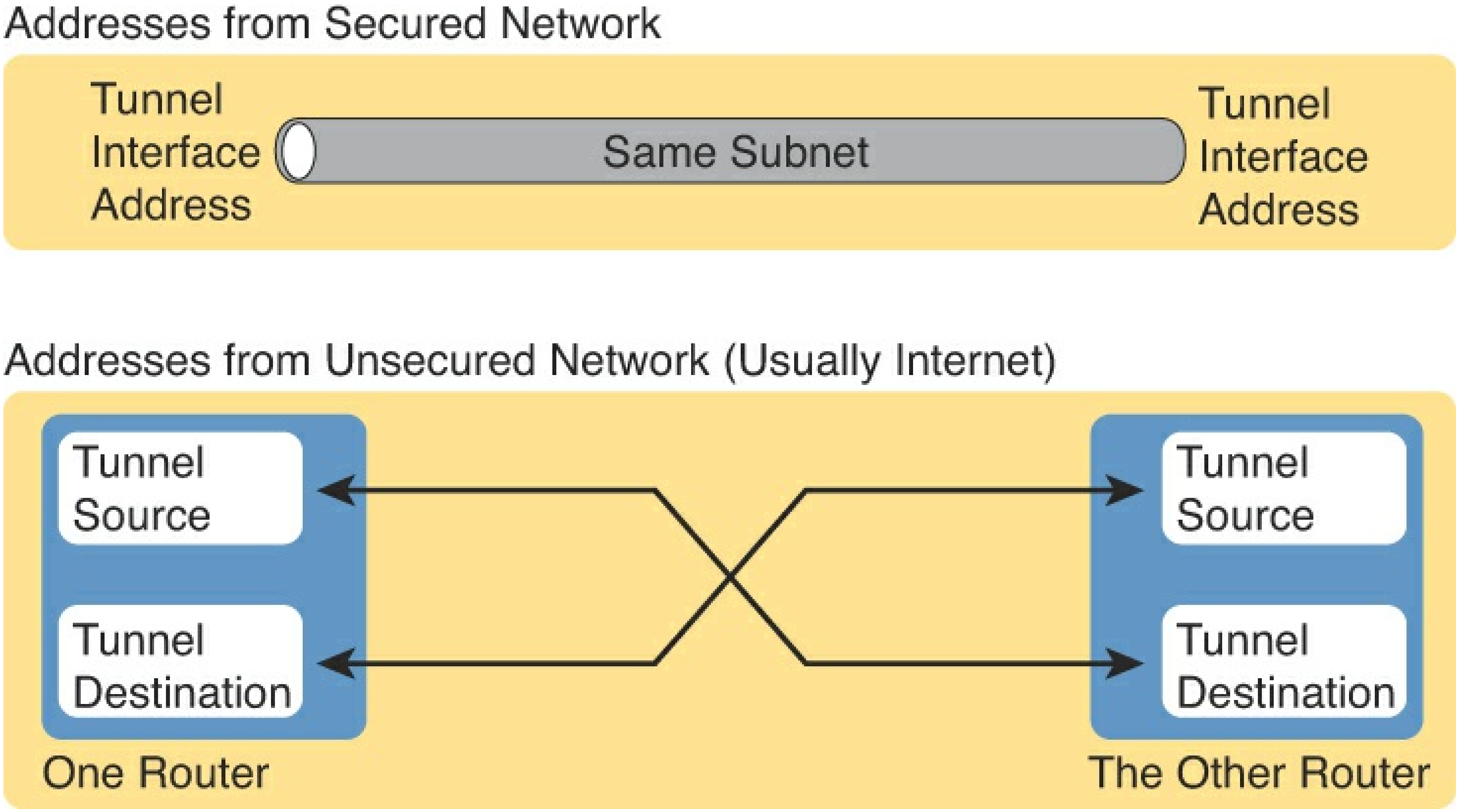

Addresses from Secured Network
Tunnel Interface Address
Same Subnet
Tunnel Interface Address
Addresses from Unsecured Network (Usually Internet)
Tunnel Source
Tunnel Destination
Tunnel Source
Tunnel Destination
One Router
The Other Router

Figure 7-12. GRE Tunnel Configuration: Relationship of Parameters

The following list details the configuration steps on each router:

Key Topic

Step 1. Create a tunnel interface using the **interface tunnel** *number* command. The interface numbers have local meaning only and do not have to match between the two routers.

Step 2. Assign an IP address to the tunnel interface with the **ip address** *address mask* command, using a subnet from the secure network's address range. The two routers on the tunnel should use addresses from the same subnet.

Step 3. Configure the tunnel's source IP address in the public part of the network with the **tunnel source** *interface* or the **tunnel source** *ip-address* interface subcommand. If referring to an interface, the local router uses the IP address configured on the listed interface. (This value must match the other router's tunnel destination.)

Step 4. Configure the tunnel's destination IP address in the public part of the network with the **tunnel destination** *ip-address* command. (This value must match the IP address used by the other router as its tunnel source IP address.)

Step 5. Configure the routers to use the tunnel with IP routes, either by enabling a dynamic routing protocol on the tunnel or by configuring static IP routes.

As usual, an example can help quite a bit. The example, as you probably guessed, matches the example used throughout the last several pages. R1 and R2 form a tunnel using public addresses 1.1.1.1 and 2.2.2.2, respectively. The tunnel uses subnet 10.1.3.0/24, with R1 and R2 using IP addresses 10.1.3.1 and 10.1.3.2, respectively. Example 7-1 shows the configuration on R1, and Example 7-2 shows the configuration on R2.

Example 7-1. Tunnel Configuration on R1

Click here to view code image

```
R1# show running-config
! Only the related configuration is listed

interface serial 0/0/0
ip address 1.1.1.1 255.255.255.0
!
interface Tunnel0
ip address 10.1.3.1 255.255.255.0
tunnel source Serial0/0/0
tunnel destination 2.2.2.2
!
! The OSPF configuration enables OSPF on the tunnel interface as well.
```

```
router ospf 1
network 10.0.0.0 0.255.255.255 area 0
```

Example 7-2. Tunnel Configuration on R2

Click here to view code image

```
R2# show running-config
! Only the related configuration is listed
interface serial 0/0/1
ip address 2.2.2.2 255.255.255.0

!
interface Tunnel1
ip address 10.1.3.2 255.255.255.0
tunnel source Serial0/0/1
tunnel destination 1.1.1.1

! The OSPF configuration enables OSPF on the tunnel interface as well.
router ospf 1
network 10.0.0.0 0.255.255.255 area 0
```

Just to make sure the matching logic is clear, take a look at R2's configuration. R2's S0/0/1 interface has been configured with IP address 2.2.2.2. Then, under interface tunnel 1, the **tunnel source Serial0/0/1** command refers to that same interface, making R2's source IP address for the tunnel 2.2.2.2. Finally, referring back up to R1's configuration, its **tunnel destination 2.2.2.2** command clearly refers to the same IP address used by R2 as its source address. The same trail can be checked for R1's source address of 1.1.1.1 and R2's destination address 1.1.1.1.

Verifying a GRE Tunnel

The ultimate test of the tunnel is whether it can pass end-user traffic. However, some other **show** commands from the router tell us a lot about the status before trying a ping or traceroute from the user's device.

First, because the tunnel acts very much like a serial link, with interfaces on both routers, the usual commands that list interface status, IP addresses, and IP routes all show information about the GRE tunnel. For instance, Example 7-3 shows the familiar **show ip interface brief** command on R1, with R1's tunnel0 interface highlighted.

Example 7-3. Displaying the Interface State and IP Addresses, Including the Tunnel Interface

Click here to view code image

```
R1# show ip interface brief
Interface IP-Address OK? Method Status Protocol
GigabitEthernet0/0 10.1.1.9 YES manual up up
GigabitEthernet0/1 unassigned YES manual administratively down down
Serial0/0/0 1.1.1.1 YES manual up up
Serial0/0/1 unassigned YES manual administratively down down
Tunnel0 10.1.3.1 YES manual up up
```

The **show interfaces tunnel** *interface-number* command lists many counters plus the configuration settings, in addition to the interface status. Example 7-4 lists a sample, again for R1's Tunnel0 interface. Note that it lists the local router (R1) configuration of the source (1.1.1.1) and destination (2.2.2.2) IP addresses, and it confirms the use of GRE encapsulation, as highlighted in the example.

Example 7-4. Tunnel Interface Details

Click here to view code image

```
R1# show interfaces tunnel0
Tunnel0 is up, line protocol is up
Hardware is Tunnel
Internet address is 10.1.3.1/24
MTU 17916 bytes, BW 100 Kbit/sec, DLY 50000 usec,
reliability 255/255, txload 1/255, rxload 1/255
Encapsulation TUNNEL, loopback not set
Keepalive not set
```

```
Tunnel source 1.1.1.1 (Serial0/0/0), destination 2.2.2.2
Tunnel Subblocks:
src-track:
Tunnel0 source tracking subblock associated with Serial0/0/0
Set of tunnels with source Serial0/0/0, 1 member (includes iterators), on interface <OK>
Tunnel protocol/transport GRE/IP
! Lines omitted for brevity
```

Although a working tunnel interface is important, the routers will not use the tunnel interface unless routes try to forward packets over the tunnel interface. The configuration in this example shows that OSPF has been enabled on all interfaces in Class A network 10.0.0.0, the secure part of the internetwork. As a result, the routers should exchange OSPF routes and learn the same routes shown in earlier Figure 7-7. Example 7-5 shows proof, with R1 listing an OSPF-learned route to R2’s LAN subnet of 10.1.2.0/24.

Example 7-5. R1 Routes in Network 10.0.0.0

Click here to view code image

```
R1# show ip route 10.0.0.0
Routing entry for 10.0.0.0/8, 5 known subnets
Attached (4 connections)
Variably subnetted with 2 masks
C 10.1.1.0/24 is directly connected, GigabitEthernet0/0
L 10.1.1.9/32 is directly connected, GigabitEthernet0/0
O 10.1.2.0/24 [110/1001] via 10.1.3.2, 00:07:55, Tunnel0
C 10.1.3.0/24 is directly connected, Tunnel0
L 10.1.3.1/32 is directly connected, Tunnel0
! Lines omitted for brevity
```

Note

The **show ip route 10.0.0.0** command lists the known routes inside network 10.0.0.0.

Finally, to prove the tunnel can forward traffic, the user can generate some traffic, or a handy extended ping or traceroute can serve as well. Example 7-6 shows an extended traceroute, sourced from R1’s LAN IP address of 10.1.1.9, and sent to server 1’s 10.1.2.2 IP address.

Example 7-6. Extended Traceroute Shows the Tunnel Is Working

Click here to view code image

```
R1# traceroute
Protocol [ip]:
Target IP address: 10.1.2.2
Source address: 10.1.1.9
Numeric display [n]:
Timeout in seconds [3]:
Probe count [3]:
Minimum Time to Live [1]:
Maximum Time to Live [30]:
Port Number [33434]:
Loose, Strict, Record, Timestamp, Verbose[none]:
Type escape sequence to abort.
Tracing the route to 10.1.2.2
VRF info: (vrf in name/id, vrf out name/id)
1 10.1.3.2 0 msec 4 msec 0 msec
2 10.1.2.2 4 msec 4 msec 0 msec
R1#
```

Example 7-6 shows that the traceroute completes, and it also lists R2’s tunnel IP address (10.1.3.2) as the first router in the route. Note that the traceroute does not list any routers in the unsecure part of the network, because the packets created by the traceroute command get encapsulated and sent from R1 to R2, just like any other packet.

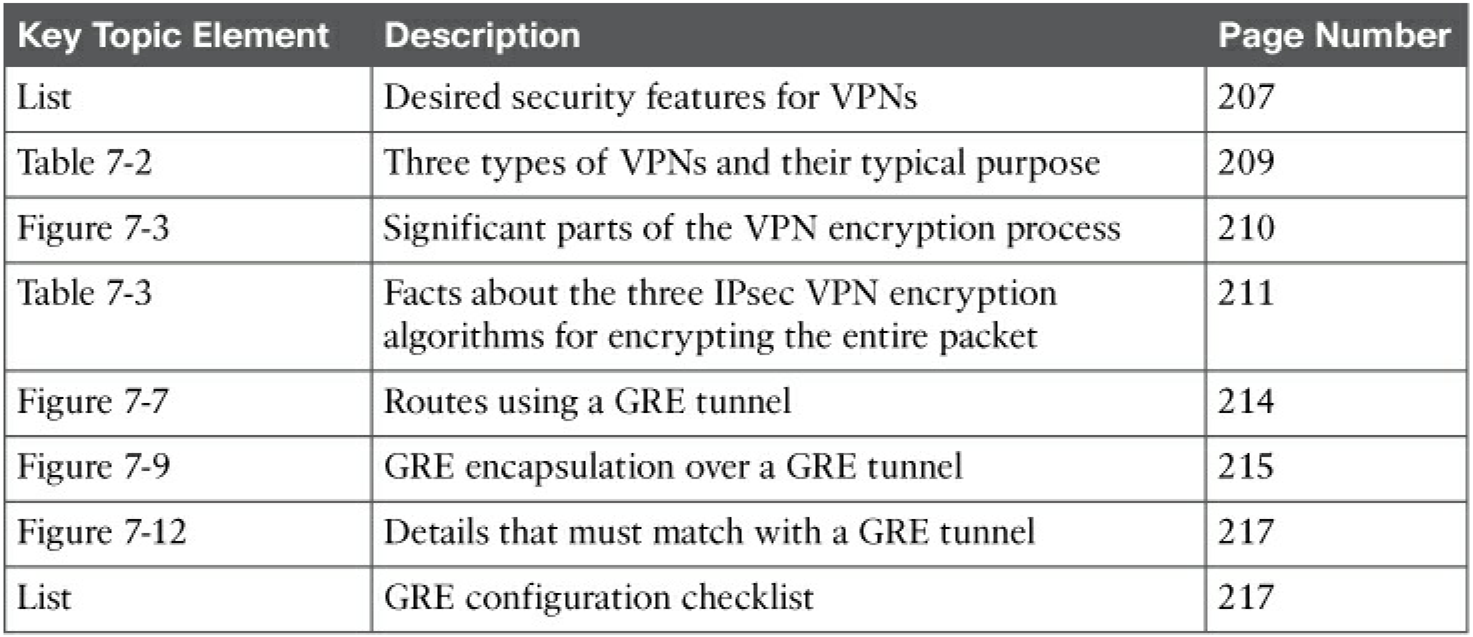
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 7-4 lists these key topics and where each is discussed.

Key Topic

Table 7-4. Key Topics for Chapter 7



Key Topic Element	Description	Page Number
List	Desired security features for VPNs	207
Table 7-2	Three types of VPNs and their typical purpose	209
Figure 7-3	Significant parts of the VPN encryption process	210
Table 7-3	Facts about the three IPsec VPN encryption algorithms for encrypting the entire packet	211
Figure 7-7	Routes using a GRE tunnel	214
Figure 7-9	GRE encapsulation over a GRE tunnel	215
Figure 7-12	Details that must match with a GRE tunnel	217
List	GRE configuration checklist	217

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix D, “Memory Tables,” or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix E, “Memory Tables Answer Key,” includes completed tables and lists to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22 directs you in how to use these terms for late-stage preparation for the exam.

IPsec
shared key
SSL
VPN
VPN client
generic routing encapsulation (GRE)
GRE tunnel

Command Reference to Check Your Memory

Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To check to see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table with a piece of paper, read the descriptions on the right side, and see whether you remember the command.

Table 7-5. Chapter 7 Configuration Command Reference

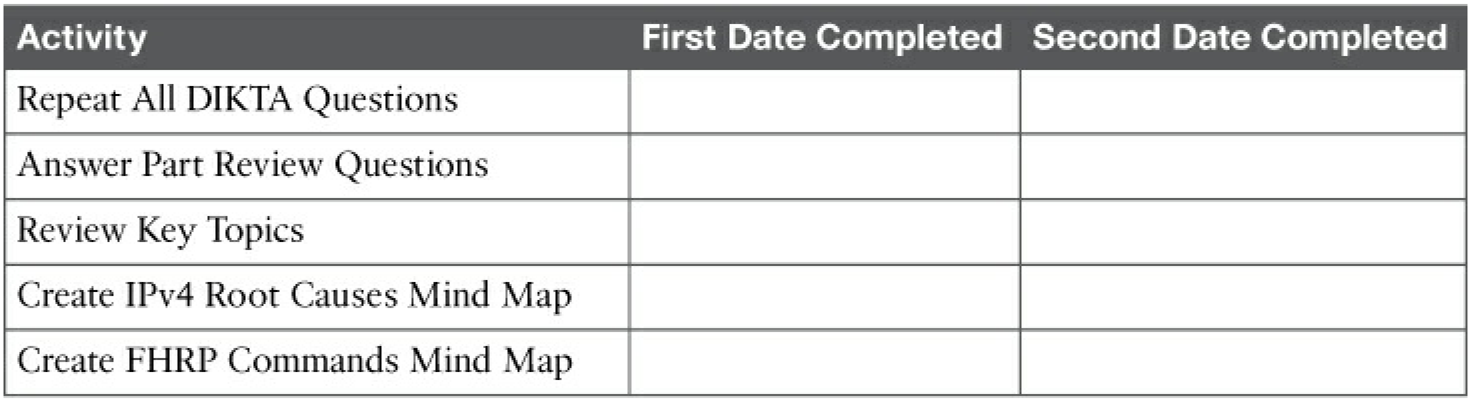
Table 7-5. Chapter 7 Configuration Command Reference

Command	Description
tunnel source *interface-type interface-number*	Tunnel interface subcommand that defines the source IP address of the tunnel on the local router, but indirectly; the router uses the IP address configured on the listed IP address.
tunnel source *ip-address*	Tunnel interface subcommand that directly defines the source IP address of the tunnel on the local router.
tunnel destination *ip-address*	Tunnel interface subcommand that defines the destination IP address of the tunnel, which exists on the other end of the tunnel.
tunnel mode gre	Tunnel interface subcommand that defines the mode of the tunnel, which must match on both ends of the tunnel. The default is **gre**.

Part II Review

Keep track of your part review progress with the checklist in Table P2-1. Details about each task follow the table.

Table P2-1. Part II Part Review Checklist



Activity	First Date Completed	Second Date Completed
Repeat All DIKTA Questions		
Answer Part Review Questions		
Review Key Topics		
Create IPv4 Root Causes Mind Map		
Create FHRP Commands Mind Map		

Repeat All DIKTA Questions

For this task, answer the "Do I Know This Already?" questions again for the chapters in Part II of this book using the PCPT software. See the section "How to View Only DIKTA Questions by Part" in the Introduction to this book to learn how to make the PCPT software show you DIKTA questions for this part only.

Answer Part Review Questions

For this task, answer the Part Review questions for this part of the book using the PCPT software. See the section "How to View Only DIKTA Questions by Part" in the Introduction to this book to learn how to make the PCPT software show you DIKTA questions for this part only.

Review Key Topics

Key Topic

Browse back through the chapters, and look for the Key Topic icons. If you do not remember some details, take the time to reread those topics.

Create IPv4 Root Causes Mind Map

Chapters 4 and 5 focus on how to troubleshoot problems with IPv4 networks. For this first Part Review mind map, work through all the items you can think of that can fail and cause a problem in an IPv4 network. In other words, think about the root causes. Then organize those into a mind map.

To organize the mind map, once you see several root causes that are related, group those root causes by whatever category comes to mind. These might be the same kinds symptoms you would see when doing problem isolation. For instance, you might note root causes about Dynamic Host Configuration Protocol (DHCP), like a router missing its DHCP Relay configuration (**ip helper-address**), and another cause that no IP connectivity exists to the DHCP server. So, group these DHCP root causes together in one category, something like Host DHCP. Figure P2-1 shows an example.

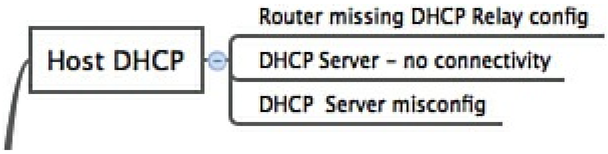

Host DHCP
Router missing DHCP Relay config
DHCP Server – no connectivity
DHCP Server misconfig

Figure P2-1. Subset Example of the IPv4 Root Cause Mind Map

> **Note**
>
> For more information about mind mapping, see the section "About Mind Maps" in the Introduction to this book.

Create FHRP Commands Mind Map

This part also introduced the configuration and verification details of three features: Hot Standby Router Protocol (HSRP), Gateway Load Balancing Protocol (GLBP), and generic routing encapsulation (GRE) tunnels. Create a mind map that organizes the commands by each of these three topics, and inside each topic organize the commands as either configuration or verification commands.

DVD Appendix F, “Mind Map Solutions,” provides sample mind map answers.

Part III: IP Version 4 Routing Protocols

Chapter 8: Implementing OSPF for IPv4

Chapter 9: Understanding EIGRP Concepts

Chapter 10: Implementing EIGRP for IPv4

Chapter 11: Troubleshooting IPv4 Routing Protocols

Part III Review

TCP/IP networks need IP routes. Part III collects four chapters focused on the IPv4 routing protocols discussed within the scope of ICND2: OSPF Version 2 (Chapter 8), EIGRP (Chapters 9 and 10), and a chapter focused on how to troubleshoot both OSPFv2 and EIGRP (Chapter 11). Note that Chapter 8 adds to a topic that the ICND1 book has already discussed in some detail, and Chapters 9 and 10 discuss EIGRP, which was not explained in any depth in the ICND1 book.

Chapter 8. Implementing OSPF for IPv4

This chapter covers the following exam topics:

- **IP Routing Technologies**
- Configure and verify OSPF (single area)
  - neighbor adjacencies
  - OSPF states
  - Discuss Multi area
  - Configure OSPF v2
  - Router ID
  - LSA types
- Differentiate methods of routing and routing protocols
  - Administrative distance
  - metric
  - next hop

Cisco happened to put some Open Shortest Path First Version 2 (OSPFv2) topics into the ICND1 exam and some into the ICND2 exam. So, this chapter takes the three perspectives on OSPFv2 discussed for ICND1—concepts, configuration, and verification—and takes each a step or two further.

In particular, this chapter takes a long look at OSPFv2 concepts. It discusses specific link-state advertisement (LSA) types, how OSPF does path determination by calculating the metric for each route, and more details on the hidden OSPF processes. In the second major section, this chapter examines multi-area configuration and how to influence path determination by changing the OSPF interface costs. Finally, the verification discussion focuses on multi-area details and the new concepts about LSAs.

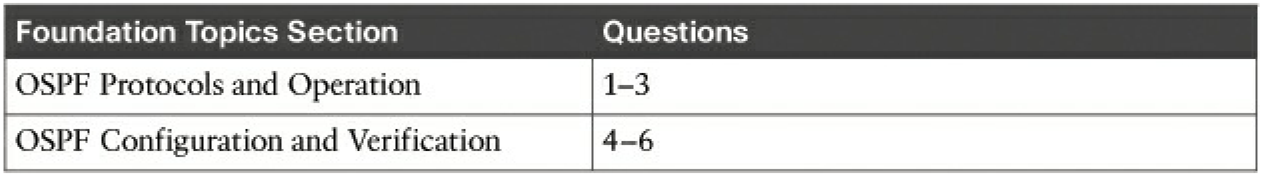
Depending on your own personal reading and study plan, this chapter may or may not present a big challenge. Those of you headed toward the one-exam path to CCNA, using one reading plan, may have read the ICND1 book's OSPFv2 coverage recently (Chapter 17 of that book). Others of you, particularly those taking the two-exam path toward CCNA Routing and Switching, may have last thought about OSPFv2 a month or two ago.

This chapter does review the most important OSPFv2 concepts and configuration steps from the ICND1 book. However, if it has been a while, it might be worth a few minutes of review of your ICND1 OSPFv2 notes before jumping into this chapter.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the Exam Preparation Tasks section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 8-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
OSPF Protocols and Operation	1–3
OSPF Configuration and Verification	4–6

1. Router R1, an internal router in OSPFv2 area 51, has an LSDB that includes some Type 1, some Type 2, and some Type 3 LSAs. Which of these types of LSAs could R1 not possibly have created inside area 51?
   - **a.** Type 1
   - **b.** Type 2
   - **c.** Type 3
   - **d.** R1 would be allowed to create all three types.
2. A company has a network with 15 routers and 40 subnets and uses OSPFv2. Which of the following is considered an advantage of using a single-area design as opposed to a multi-area design?
   - **a.** Reduces the processing overhead on most routers.
   - **b.** Status changes to one link may not require SPF to run on all other routers.
   - **c.** Simpler planning and operations.
   - **d.** Allows for route summarization, reducing the size of IP routing tables.
3. Which of the following OSPF neighbor states is expected when the exchange of topology information is complete between two OSPF neighbors?
   - **a.** 2-way
   - **b.** Full
   - **c.** Up/up

   d. Final

4. Routers R1, R2, and R3 are internal routers in areas 1, 2, and 3, respectively. Router R4 is an ABR connected to the backbone area (0) and to areas 1, 2, and 3. Which of the following answers describes the configuration on router R4, which is different from the other three routers, that makes it an ABR?

   a. The **abr enable** router subcommand.

   b. The **network** router subcommands refer to a single nonbackbone area.

   c. The **network** router subcommands refer to multiple areas, including the backbone.

   d. The router has an interface in area 0, whereas an OSPF neighbor's interface sits in a different area.

5. Which of the following configuration settings on a router does not influence which IPv4 route a router chooses to add to its IPv4 routing table when using OSPFv2?

   a. auto-cost reference-bandwidth

   b. delay

   c. bandwidth

   d. ip ospf cost

6. An engineer connects to router R1 and issues a **show ip ospf neighbor** command. The status of neighbor 2.2.2.2 lists Full/BDR. What does the BDR mean?

   a. R1 is an Area Border Router.

   b. R1 is a backup designated router.

   c. Router 2.2.2.2 is an Area Border Router.

   d. Router 2.2.2.2 is a backup designated router.

Answers to the "Do I Know This Already?" quiz:

1 C **2** C **3** B **4** C **5** B **6** D

Foundation Topics

OSPF Protocols and Operation

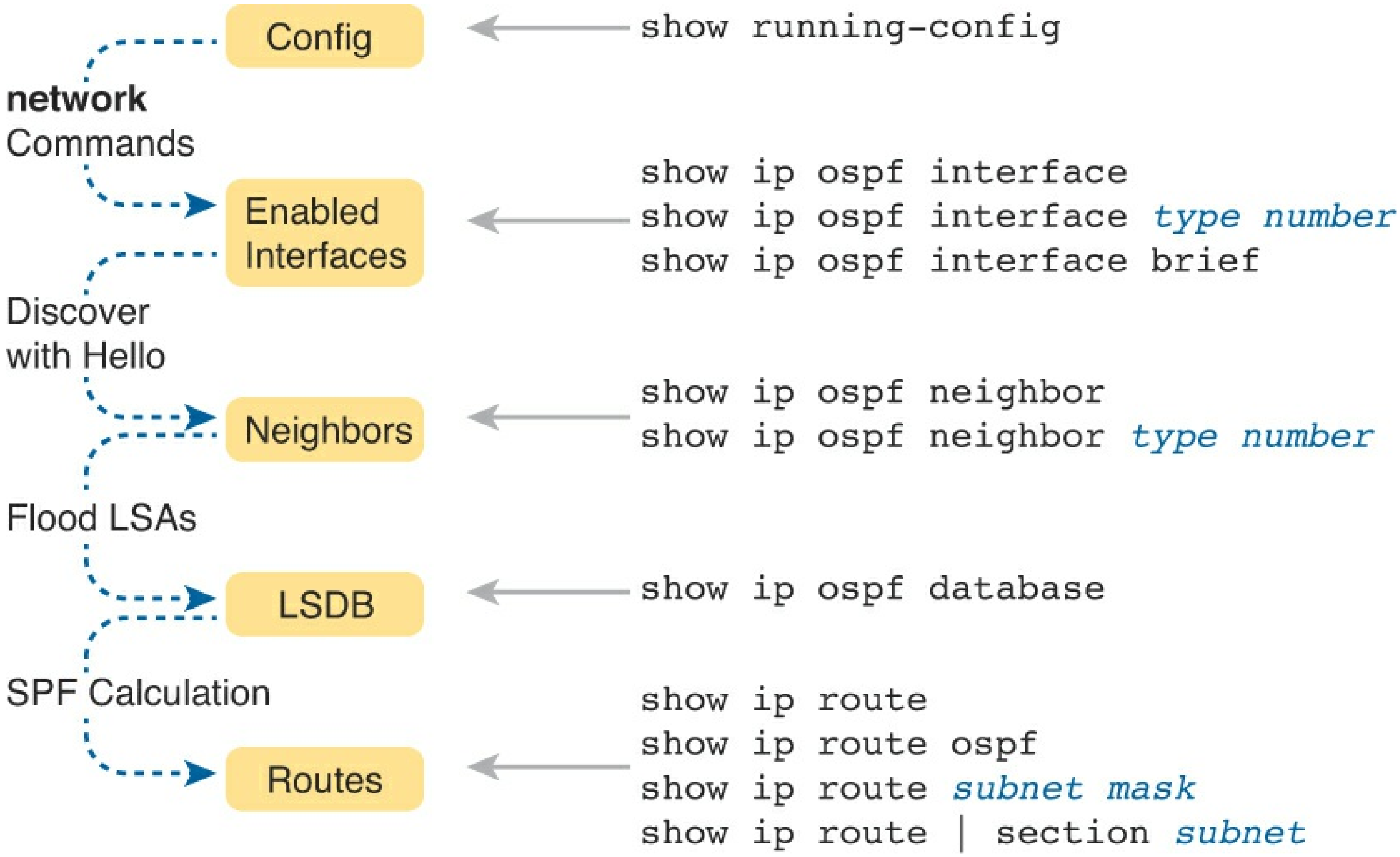
Between the two routing protocols discussed in depth in this book—OSPF and EIGRP—OSPF happens to have more rules, more processes, and more theoretical details. This first of two major sections of the chapter examines many of these details about OSPF concepts. These details help prepare network engineers who take over the problem from the first-and second-level support in a network to work the problem and find the true root cause of any OSPF problem.

This first section of the chapter lays the conceptual groundwork, and the second section then works through some new related configuration. Chapter 11, "Troubleshooting IPv4 Routing Protocols," works through several specific troubleshooting scenarios for OSPF.

OSPF Overview

If you think back to what you already learned about OSPFv2 (OSPF for IPv4 networks) in the ICND1 book, or for the ICND1 exam, you probably remember that the big ideas follow a logical sequence. Figure 8-1 shows that sequence on the left, from top to bottom.

Key Topic



```
show running-config

show ip ospf interface
show ip ospf interface type number
show ip ospf interface brief

show ip ospf neighbor
show ip ospf neighbor type number

show ip ospf database

show ip route
show ip route ospf
show ip route subnet mask
show ip route | section subnet
```

Figure 8-1. Link-State Hello Packets

Take a moment to consider the steps in the figure. That is, start with the configuration, which enables OSPFv2 on some interfaces by using **network** commands. As a result, the router sends and receives OSPF Hellos on those interfaces, hoping to discover OSPF neighbors. Once a potential neighbor is discovered, the neighbors check each others' parameters, and if they pass, the neighbors flood their known LSAs to each other, completing their link-state databases (LSDB). Finally, the router's shortest path first (SPF) algorithm calculates the best route to each subnet, putting those routes into the IPv4 routing table.

In fact, Figure 8-1 summarizes the big concepts from the ICND1 book's Chapter 17, and summarizes that same chapter's verification commands on the right.

The OSPF router ID (RID), introduced back in the ICND1 book, plays a big role in many of the OSPFv2 internals discussed in this chapter. To review the basics, the RID serves as a router's unique identifier for OSPFv2. Each router then uses RIDs for many purposes, such as the following:

- When routers send a Hello message, they basically state "Hello, my RID is...."
- Neighbors identify each other by their RID, as listed in the output of the **show ip ospf neighbor** command.
- Many LSAs list the RID of one of the routers.

Because OSPFv2 uses RIDs so much, most network engineers choose to control the RID setting with configuration. It is much easier to operate an OSPFv2 network if everyone knows the RID of each router or can easily predict them. Most engineers choose an OSPF RID numbering plan with either a list of routers and their OSPF RIDs, or an easy way to predict each router's RID. For example, R1 could use RID 172.16.1.1, R2 could use 172.16.2.2, R3 could use 172.16.3.3, and so on.

The following list shows the sequential steps that a router completes when choosing its own RID when the router reloads and brings up the OSPF process:

Key Topic

1. Use the value in the **router-id** *rid* OSPF subcommand.
2. If unset per Step 1, among all loopback interfaces that have an IP address configured, and for which the interface has an interface status of up, choose the highest numeric IPv4 address among these loopback interfaces.
3. If unset per Steps 1 and 2, use the same logic as Step 2, but for all nonloopback interfaces.

Finally, one last note on the OSPF RID: Each router chooses its OSPF RID when OSPF is initialized. Initialization happens during the initial load of IOS or with the **clear ip ospf process** command. For instance, if you add a loopback interface and IPv4 address later, after configuring OSPFv2, the OSPFv2 process will not consider (as RID) the IP address of that new loopback interface until the next time the OSPF process starts.

Also note that if the OSPF process simply cannot find a RID to use, the OSPF process cannot work.

Becoming Neighbors and Exchanging the LSDB

The whole point of using OSPFv2 is to learn IPv4 routes. To do that, OSPFv2 routers must become neighbors, and then exchange the LSAs in their link-state databases (LSDB). The next few pages work through some particulars of the OSPFv2 protocols and neighbor states.

> **Note**
>
> OSPF protocols work slightly differently on point-to-point links (simpler) versus Ethernet links (more complex). To keep the next examples simpler, for easier learning, the examples assume the rules for point-to-point links. Later, in the "Using Designated Routers on Ethernet" section, you'll read about variations in OSPF that happen on other topologies like Ethernet.

Agreeing to Become Neighbors

When a point-to-point link is down, OSPF cannot have any neighbors over that link. When the link comes up, the routers on the ends of the link go through a couple of interim neighbor states while working through important steps, such as discovering the existence of the neighbor, checking parameters to see whether they are allowed to become neighbors, and exchanging their LSAs in a process known as database exchange.

Figure 8-2 shows several of the neighbor states used by the early formation of an OSPF neighbor relationship. The figure shows the Hello messages in the center and the resulting neighbor states on the left and right edges of the figure.

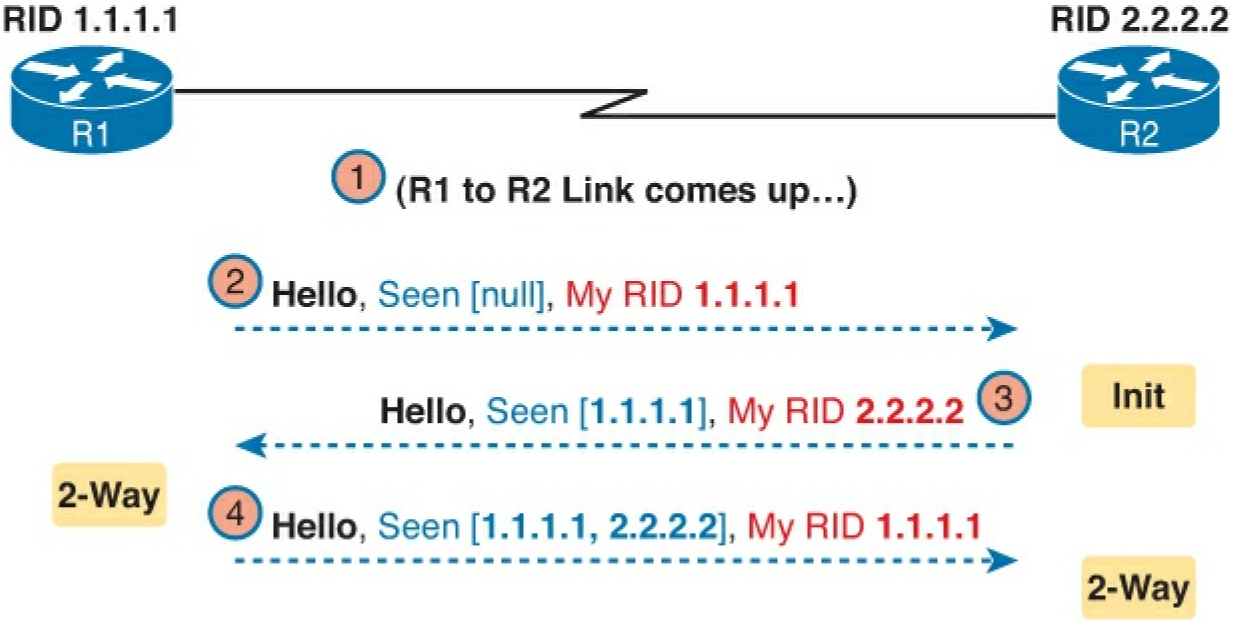

RID 1.1.1.1
RID 2.2.2.2
R1
R2
① (R1 to R2 Link comes up...)
② Hello, Seen [null], My RID 1.1.1.1
Hello, Seen [1.1.1.1], My RID 2.2.2.2 ③
Init
2-Way
④ Hello, Seen [1.1.1.1, 2.2.2.2], My RID 1.1.1.1
2-Way

Figure 8-2. Early Neighbor States

Following the steps in the figure, the scenario begins with the link down, so the routers have no knowledge of each other as OSPF neighbors. As a result, they have no state (status) information about each other as neighbors, and they would not list each other in the output of the **show ip ospf neighbor** command. At Step 2, R1 sends the first Hello, so R2 learns of the existence of R1 as an OSPF router. At that point, R2 lists R1 as a neighbor, with an interim state of Init.

The process continues at Step 3, with R2 sending back a Hello. This message tells R1 that R2 exists, and it allows R1 to move to a 2-way state. At Step 4, R2 receives the next Hello from R1, and R2 can also move to a 2-way state.

To see more about why the routers move to the next state, rescan the detail in these messages and look for the notes listed as "seen." When a router receives a Hello from a potential neighbor, and that potential neighbor's parameters match with the local router's parameters, the local router believes it has seen a new legitimate neighbor on the link. For example, the message labeled as Step 3 in the figure, from R2 to R1, lists "Seen [1.1.1.1]," meaning R2 received R1's earlier Hello (at Step 2) and that R2 thinks the parameters all match so that the two routers can become neighbors.

Once through these early steps, each router reaches a 2-way state with their neighbor. At that point, the following two major facts are true:

- The router received a Hello from the neighbor, with that router's own RID listed as being seen by the neighbor.
- The router has checked all the parameters in the Hello received from the neighbor, with no problems. The router is willing to become a neighbor.

Fully Exchanging LSAs with Neighbors

The OSPF neighbor state 2-way means that the router is available to exchange its LSDB with the neighbor. In other words, it is ready to begin a 2-way exchange of the LSDB. So, once two routers on a point-to-point link reach the 2-way state, they can immediately move on to the process of database exchange.

The database exchange process can be quite involved, with several OSPF messages and several interim neighbor states. This chapter is more concerned with a few of the messages and the final state when database exchange has completed: the full state.

After two routers decide to exchange databases, they do not simply send the contents of the entire database. First, they tell each other a list of LSAs in their respective databases—not all the details of the LSAs, just a list. (Think of these lists as checklists.) Then, each router can check which LSAs it already has, and then ask the other router for only the LSAs that are not known yet.

For instance, R1 might send R2 a checklist that lists 10 LSAs (using an OSPF Database Description, or DD, packet). R2 then checks its LSDB and finds 6 of those 10 LSAs. So, R2 asks R1 (using a Link-State Request packet) to send the four additional LSAs.

Thankfully, most OSPFv2 work does not require detailed knowledge of these specific protocol steps. However, a few of the terms are used quite a bit and should be remembered. In particular, the OSPF messages that actually send the LSAs between neighbors are called a Link-State Update (LSU) packet. That is, the packet (LSU) holds data structures called LSAs. The link-state advertisements (LSA) are not packets, but rather data structures, which sit inside the LSDB and describe the topology.

Figure 8-3 pulls some of these terms and processes together, with a general example. The story picks up the example shown in Figure 8-2, with Figure 8-3 showing an example of the database exchange process between routers R1 and R2. The center shows the protocol messages, and the outer items show the neighbor states at different points in the process. Focus on two items in particular:

- The routers exchange the LSAs inside LSU packets.
- When finished, the routers reach a full state, meaning they have fully exchanged the contents of their LSDBs.

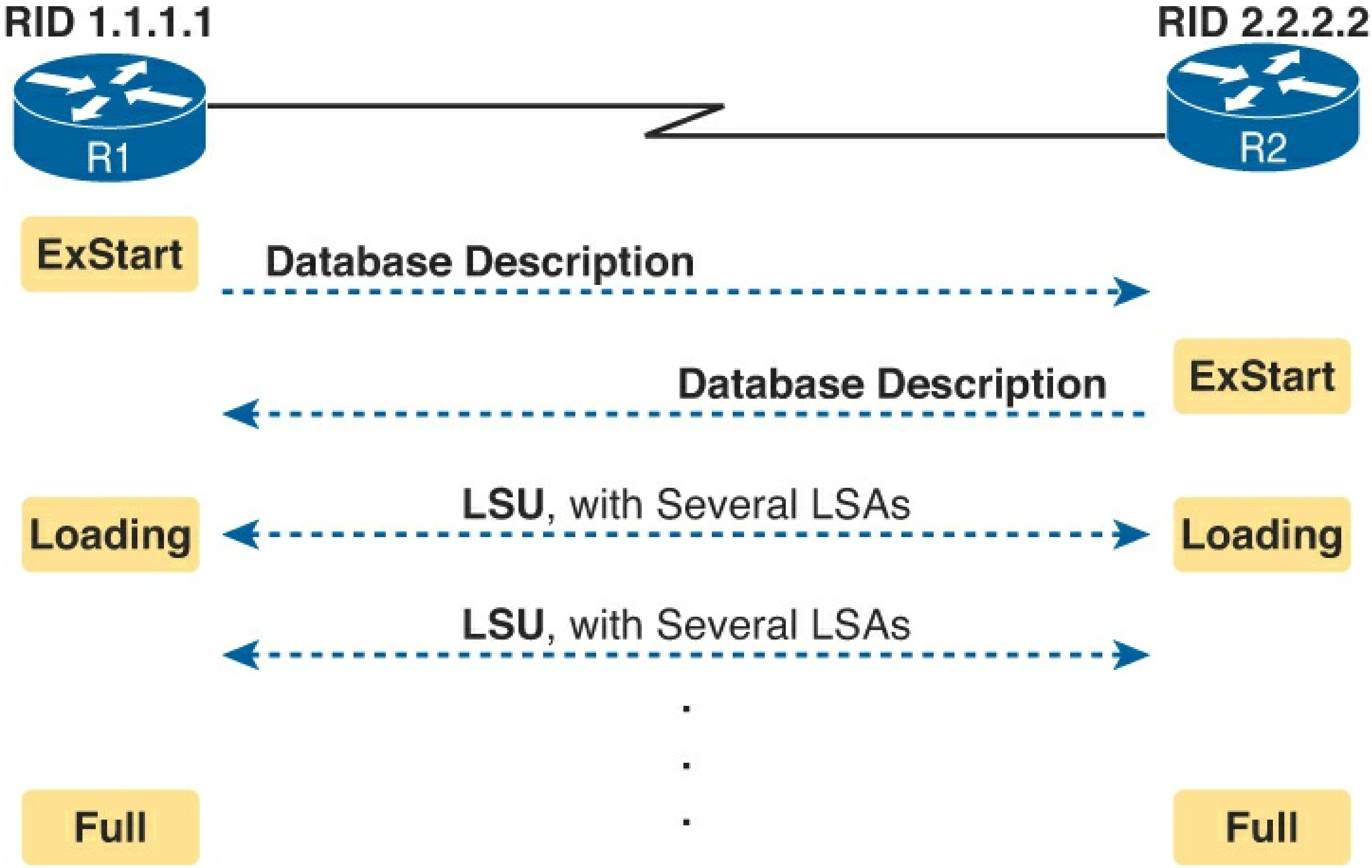


Figure 8-3. A Database Exchange Example, Ending in a Full State

Maintaining Neighbors and the LSDB

Once neighbors reach a full state, they have done all the initial work to exchange OSPF information between the two neighbors. However, neighbors still have to do some small ongoing tasks to maintain the neighbor relationship.

First, routers monitor each neighbor relationship using Hello messages and two related timers: The Hello Interval and the Dead Interval. Routers send Hellos every Hello Interval to each neighbor. Each router expects to receive a Hello from each neighbor based on the Hello Interval, so if a neighbor is silent for the length of the Dead Interval (by default 4 times as long as the Hello Interval), the loss of Hellos means that the neighbor has failed.

Next, routers must react when the topology changes as well, and neighbors play a key role in that process. When something changes, one or more routers change one or more LSAs. Then, the routers must flood the changed LSAs to each neighbor so that the neighbor can change its LSDB.

For example, imagine a LAN switch loses power, so a router's G0/0 interface fails from up/up to down/down. That router updates an LSA that shows the router's G0/0 as being down. That router then sends the LSA to its neighbors, and they in turn send it to their neighbors, until all routers again have an identical copy of the LSDB. Each router's LSDB now reflects the fact that the original router's G0/0 interface failed, so each router will then use SPF to recalculate any routes affected by the failed interface.

A third maintenance task done by neighbors is to reflood each LSA occasionally, even when the network is completely stable. By default, each router that creates an LSA also has the responsibility to reflood the LSA every 30 minutes (the default), even if no changes occur. (Note that each LSA has a separate timer, based on when the LSA was created, so there is no single big event where the network is overloaded with flooding LSAs.)

The following list summarizes these three maintenance tasks for easier review:

- Maintain neighbor state by sending Hello messages based on the Hello Interval, and listening for Hellos before the Dead Interval expires
- Flood any changed LSAs to each neighbor
- Reflood unchanged LSAs as their lifetime expires (default 30 minutes)

Using Designated Routers on Ethernet Links

OSPF behaves differently on some types of interfaces, particularly comparing point-to-point and Ethernet links. In particular, on Ethernet links, OSPF elects one of the routers on the same subnet to act as the *designated router* (DR). The DR plays a key role in how the database exchange process works, with different rules than with point-to-point links. To see how, consider the example that begins with Figure 8-4. The figure shows five OSPFv2 routers on the same Ethernet VLAN. These five OSPF routers elect one router to act as the DR, and one router to be backup DR (BDR). The figure shows A and B as DR and BDR, for no other reason than the Ethernet must have one of each.

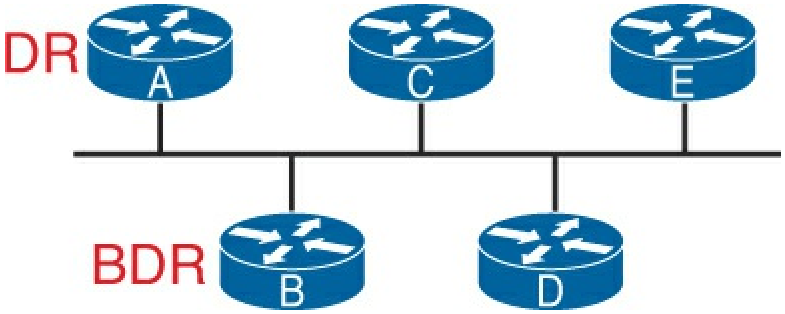


Figure 8-4. Routers A and B Elected as DR and BDR

The database exchange process on an Ethernet link does not happen between every pair of routers on the same VLAN/subnet. Instead, it happens between the DR and each of the other routers, with the DR making sure that all the other routers get a copy of each LSA. In other words, the database exchange happens over the flows shown in Figure 8-5.

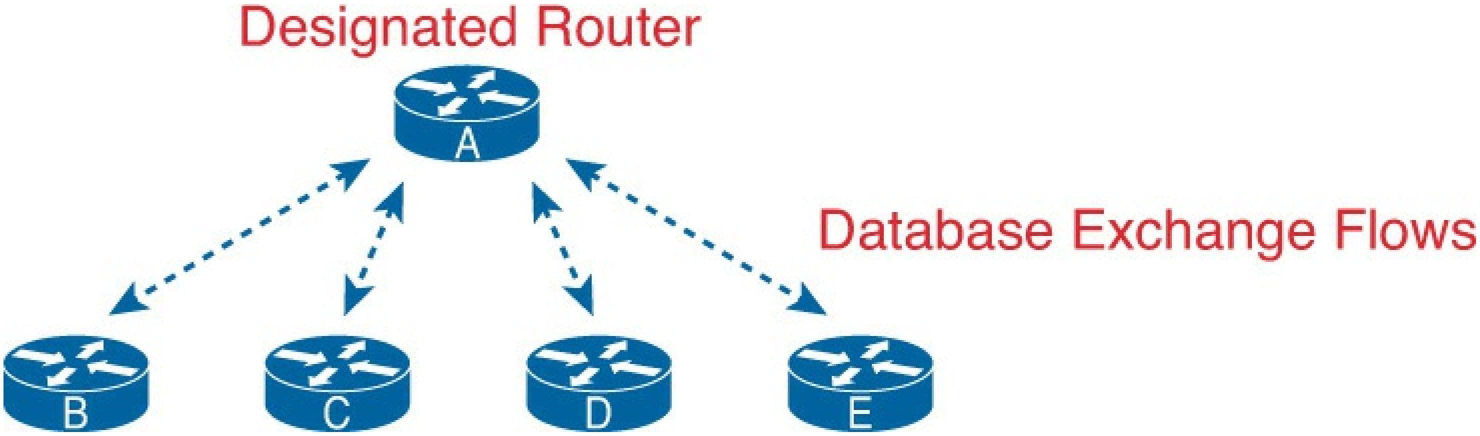


Figure 8-5. Database Exchange to and from the DR on an Ethernet

OSPF uses the BDR concept because the DR is so important to the database exchange process. The BDR watches the status of the DR and takes over for the DR if it fails. (When the DR fails, the BDR takes over, and then a new BDR is elected.)

At this point, you might be getting a little tired of some of the theory, but finally, the theory actually shows something that you may see in **show** commands on a router. Because the DR and BDR both do full database exchange with all the other OSPF routers in the LAN, they reach a full state with all neighbors. However, routers that are neither a DR nor a BDR—called *DROthers* by OSPF—never reach a full state because they do not do database exchange with each other. As a result, the **show ip ospf neighbor** command on these routers list some neighbors, permanently, in a state of 2-way, and not in a full state.

For instance, with OSPF working normally on the Ethernet LAN in Figure 8-5, a **show ip ospf neighbor** command on router C (a DROther) would show the following:

- Two neighbors (A and B, the DR and BDR, respectively) with a full state (called fully adjacent)
- Two neighbors (D and E) with a 2-way state (called adjacent)

This different behavior on OSPF neighbors on a LAN—where some neighbors reach full state and some do not—calls for the use of two more OSPF terms: *adjacent* and *fully adjacent*. Fully adjacent neighbors reach a full state, after having exchanged their LSDBs directly. Adjacent neighbors are those DROther routers that (correctly) choose to stay in 2-way state but never reach a full state. Table 8-2 summarizes these key concepts and terms related to OSPF states.

Key Topic

Table 8-2. Stable OSPF Neighbor States and Their Meanings

Neighbor State	Adjacency Lingo	Meaning
2-way	Adjacent	The neighbor has sent a Hello that lists the local router's RID in the list of seen routers, also implying that neighbor verification checks all passed. If both neighbors are DROther routers, the neighbors should remain in this state.
Full	Fully adjacent	Both routers know the exact same LSDB details and are fully adjacent, meaning they have completed the exchange of LSDB contents.

Scaling OSPF Using Areas

OSPF can be used in some networks with very little thought about design issues. You just turn on OSPF in all the routers, put all interfaces into the same area (usually area 0), and it works! Figure 8-6 shows one such network example, with 11 routers and all interfaces in area 0.

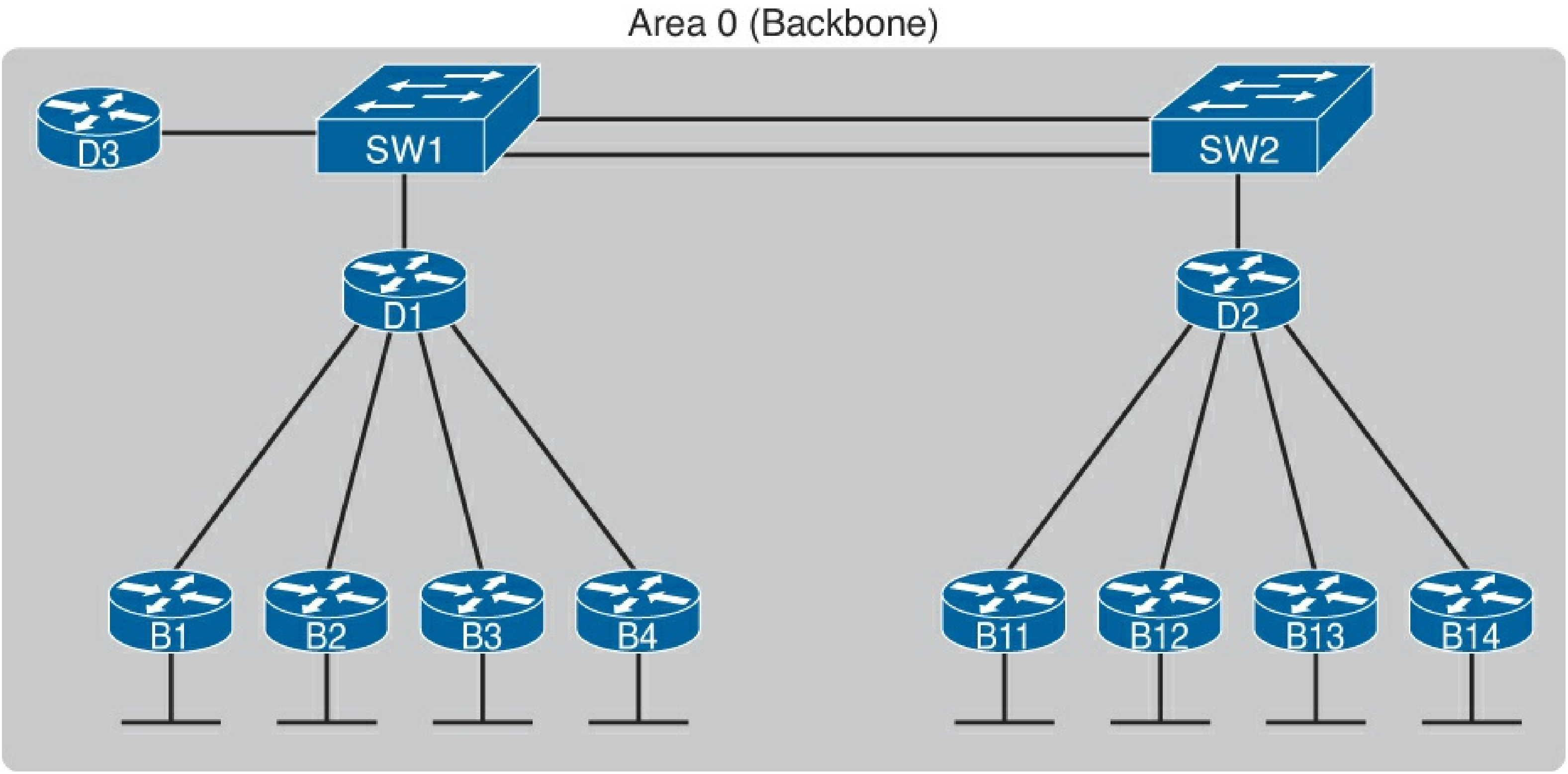


Figure 8-6. Single-Area OSPF

Larger OSPFv2 networks suffer with a single-area design. For instance, now imagine an enterprise network with 900 routers, rather than only 11, and several thousand subnets. As it turns out, the CPU time to run the SPF algorithm on all that topology data just takes time. As a result, OSPFv2 convergence time—the time required to react to changes in the network—can be slow. The routers may run low on RAM, as well. Additional problems include the following:

- A larger topology database requires more memory on each router.
- Processing the larger topology database with the SPF algorithm requires processing power that grows exponentially with the size of the topology database.
- A single interface status change, anywhere in the internetwork (up to down, or down to up), forces *every router* to run SPF again!

The solution is to take the one large LSDB and break it into several smaller LSDBs by using OSPF areas. With areas, each link is placed into one area. SPF does its complicated math on the topology inside the area, and that area's topology only. For instance, an internetwork with 1000 routers and 2000 subnets, broken in 100 areas, would average 10 routers and 20 subnets per area. The SPF calculation on a router would have to only process topology about 10 routers and 20 links, rather than 1000 routers and 2000 links.

So, how large does a network have to be before OSPF needs to use areas? Well, there is no set answer, because the behavior of the SPF process depends largely on CPU processing speed, the amount of RAM, the size of the LSDB, and so on. Generally, networks larger than a few dozen routers benefit from areas, and some documents over the years have listed 50 routers as the dividing line at which network really should use areas.

The next few pages look at how OSPF area design works, with more reasons as to why areas helps make larger OSPF networks work better.

OSPF Areas

OSPF area design follows a couple of basic rules. To apply the rules, start with a clean drawing of the internetwork, with routers, and all interfaces. Then, choose the area for each router interface, as follows:

Key Topic

- Put all interfaces connected to the same subnet inside the same area.
- An area should be contiguous.
- Some routers may be internal to an area, with all interfaces assigned to that single area.
- Some routers may be ABRs, because some interfaces connect to the backbone area, and some connect to nonbackbone areas.
- All nonbackbone areas must connect to the backbone area (area 0) by having at least one ABR connected to both the backbone area and the nonbackbone area.

Figure 8-7 shows one example. Some engineer started with a network diagram that showed all 11 routers and their links. On the left, the engineer put four serial links, and the LANs connected to branch routers B1 through B4, into area 1. Similarly, he placed the links to branches B11 through B14, and their LANs, in area 2. Both areas need a connection to the backbone area, area 0, so he put the LAN interfaces of D1 and D2 into area 0, along with D3, creating the backbone area.

Key Topic

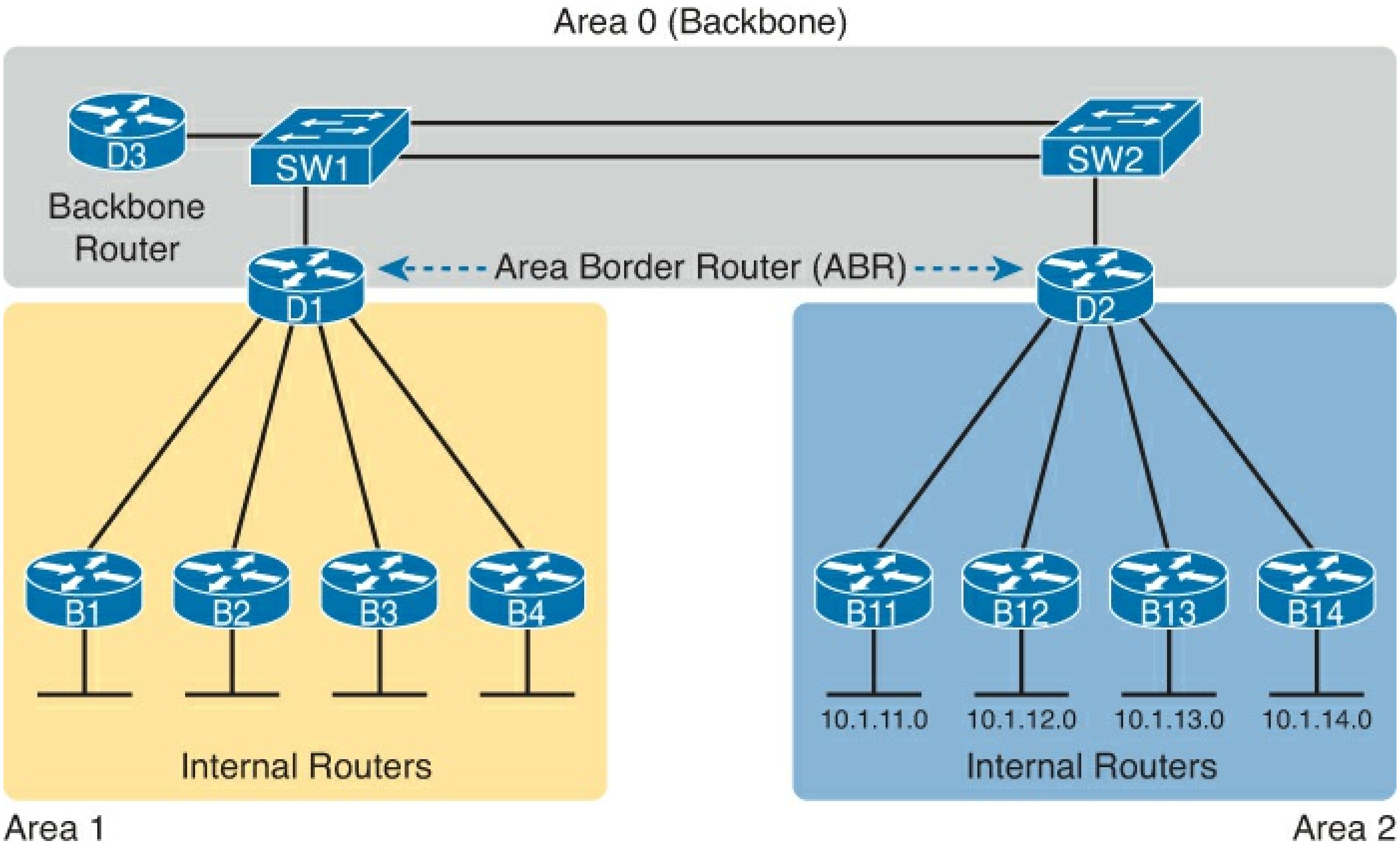

Area 0 (Backbone)
D3
SW1
SW2
Backbone Router
D1
Area Border Router (ABR)
D2
B1
B2
B3
B4
B11
B12
B13
B14
10.1.11.0
10.1.12.0
10.1.13.0
10.1.14.0
Internal Routers
Internal Routers
Area 1
Area 2

Figure 8-7. Three-Area OSPF with D1 and D2 as ABRs

The figure also shows a few important OSPF area design terms. Table 8-3 summarizes the meaning of these terms, plus some other related terms, but pay closest attention to the terms from the figure.

Key Topic

Table 8-3. OSPF Design Terminology

Term	Description
Area Border Router (ABR)	An OSPF router with interfaces connected to the backbone area and to at least one other area
Backbone router	A router in one area (the backbone area)
Internal router	A router in one area (not the backbone area)
Area	A set of routers and links that share the same detailed LSDB information, but not with routers in other areas, for better efficiency
Backbone area	A special OSPF area to which all other areas must connect—area 0
Intra-area route	A route to a subnet inside the same area as the router
Interarea route	A route to a subnet in an area of which the router is not a part

How Areas Reduce SPF Calculation Time

Figure 8-7 shows a sample area design and some terminology related to areas, but it does not show the power and benefit of the areas. To understand how areas reduce the work SPF has to do, you need to understand what changes about the LSDB inside an area, as a result of the area design.

SPF spends most of its processing time working through all the topology details, namely routers and the links that connect routers. Areas reduce SPF’s workload because, for a given area, the LSDB lists only routers and links inside that area, as shown on the left side of Figure 8-8.

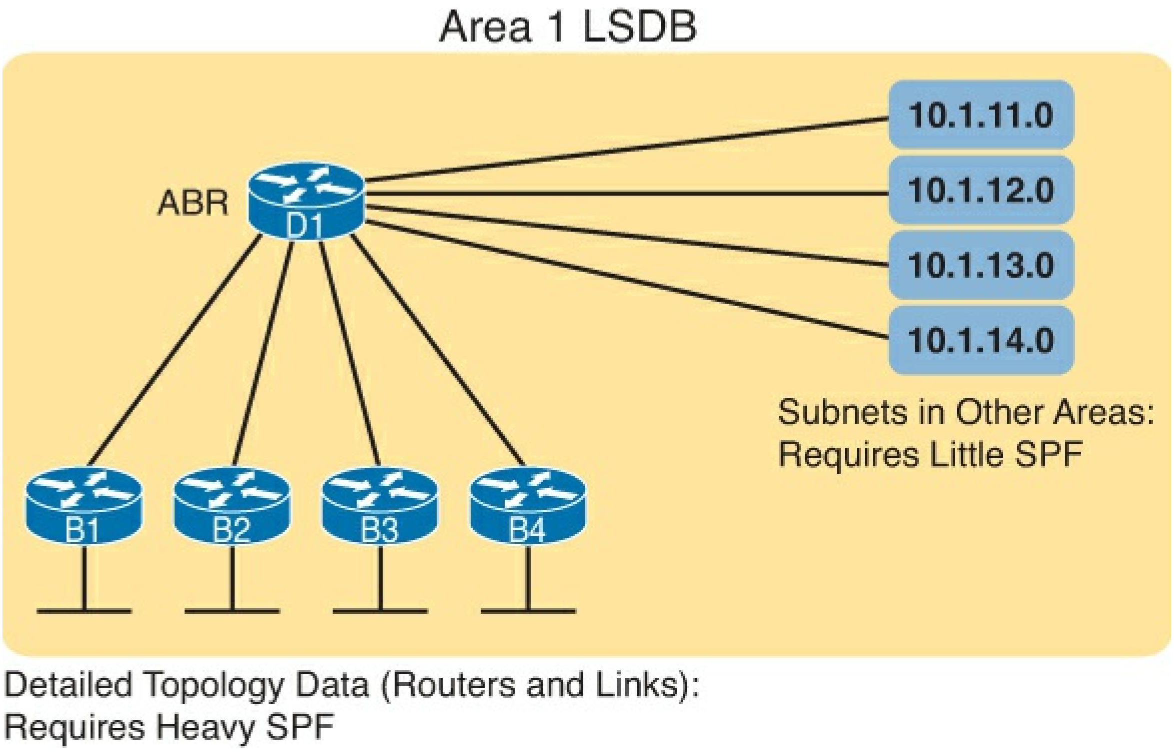


Figure 8-8. The Smaller Area 1 LSDB Concept

While the LSDB has less topology information, it still has to have information about all subnets in all areas, so that each router can create IPv4 routes for all subnets. So, with an area design, OSPFv2 uses very brief summary information about the subnets in other areas. These LSAs do not include topology information about the other areas, so they do not require much SPF processing at all. Instead, these subnets all appear like subnets connected to the ABR (in this case, ABR D1).

OSPF Area Design Advantages

In summary, using a single-area OSPF design works well for smaller OSPF networks. It avoids the added complexity, making the network slightly easier to operate. It also requires less planning effort because no one has to plan which parts of the network end up in which area.

Using multiple areas improves OSPF operations in many ways for larger networks. The following list summarizes some of the key points arguing for the use of multiple areas in larger OSPF networks:

- The smaller per-area LSDB requires less memory.
- Routers require fewer CPU cycles to process the smaller per-area LSDB with the SPF algorithm, reducing CPU overhead and improving convergence time.
- Changes in the network (for example, links failing and recovering) requires SPF calculations only on routers connected to the area where the link changed state, reducing the number of routers that must rerun SPF.
- Less information must be advertised between areas, reducing the bandwidth required to send LSAs.

Link-State Advertisements

Many people tend to get a little intimidated by OSPF LSAs when first learning about them. The output of the **show ip ospf database** command—a command that lists a summary of the output—is pretty long. Commands that look at specific LSAs list a lot more information. The details appear to be in some kind of code, using lots of numbers. It can seem like a bit of a mess.

However, if you examine LSAs while thinking about OSPF areas, and area design, some of the most common LSA types will make a lot more sense. For instance, think about the LSDB in one area, like the example shown in Figure 8-8. The topology details included routers and the links between the routers. As it turns out, OSPF defines the first two types of LSAs to define those exact details, as follows:

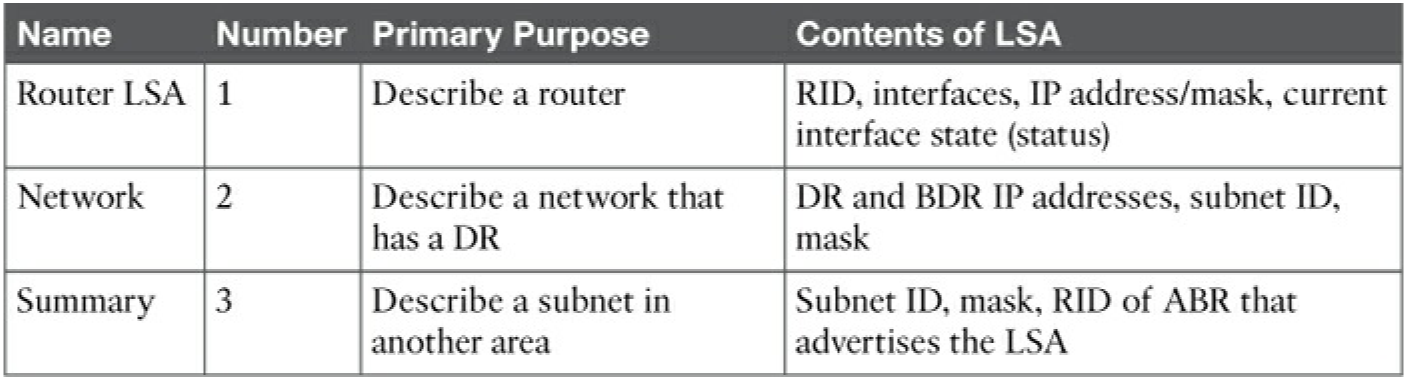
- One *router LSA* for each router in the area
- One *network LSA* for each network that has a DR plus one neighbor of the DR

Next, think about the subnets in the other areas, the ones on the right side of Figure 8-8. That brief summary information about subnets in other areas—basically just the subnet IDs and masks—exist as a third type of LSA:

- One *summary* LSA for each subnet ID that exists in a different area

The next few pages discuss these three LSA types in a little more detail; Table 8-4 lists some information about all three for easier reference and study.

Table 8-4. The Three OSPFv2 LSA Types Seen with a Multi-Area OSPF Design



Name	Number	Primary Purpose	Contents of LSA
Router LSA	1	Describe a router	RID, interfaces, IP address/mask, current interface state (status)
Network	2	Describe a network that has a DR	DR and BDR IP addresses, subnet ID, mask
Summary	3	Describe a subnet in another area	Subnet ID, mask, RID of ABR that advertises the LSA

Note

In some networks, both OSPF and other routing protocols are used. In that case, one or more routers run both OSPF and the other routing protocol, with those routers acting as an OSPF Autonomous System Border Router, or ASBR, redistributing routing information between OSPF and the other protocol. In such a case, the ASBR creates a Type 4 LSA, which describes the ASBR itself, and Type 5 LSAs for each external route learned from the other routing protocol and then advertised into OSPF.

Router LSAs Build Most of the Intra-Area Topology

OSPF needs very detailed topology information inside each area. The routers inside area X need to know all the details about the topology inside area X. And the mechanism to give routers all these details is for the routers to create and flood router (Type 1) and network (Type 2) LSAs about the routers and links in the area.

Router LSAs, also known as Type 1 LSAs, describe the router in detail. It lists a router's RID, its interfaces, its IPv4 addresses and masks, its interface state, and notes about what neighbors the router knows out its interfaces.

To see a specific instance, first review Figure 8-9. It lists internetwork topology, with subnets listed. As a small internetwork, the engineer chose a single-area design, with all interfaces in backbone area 0.

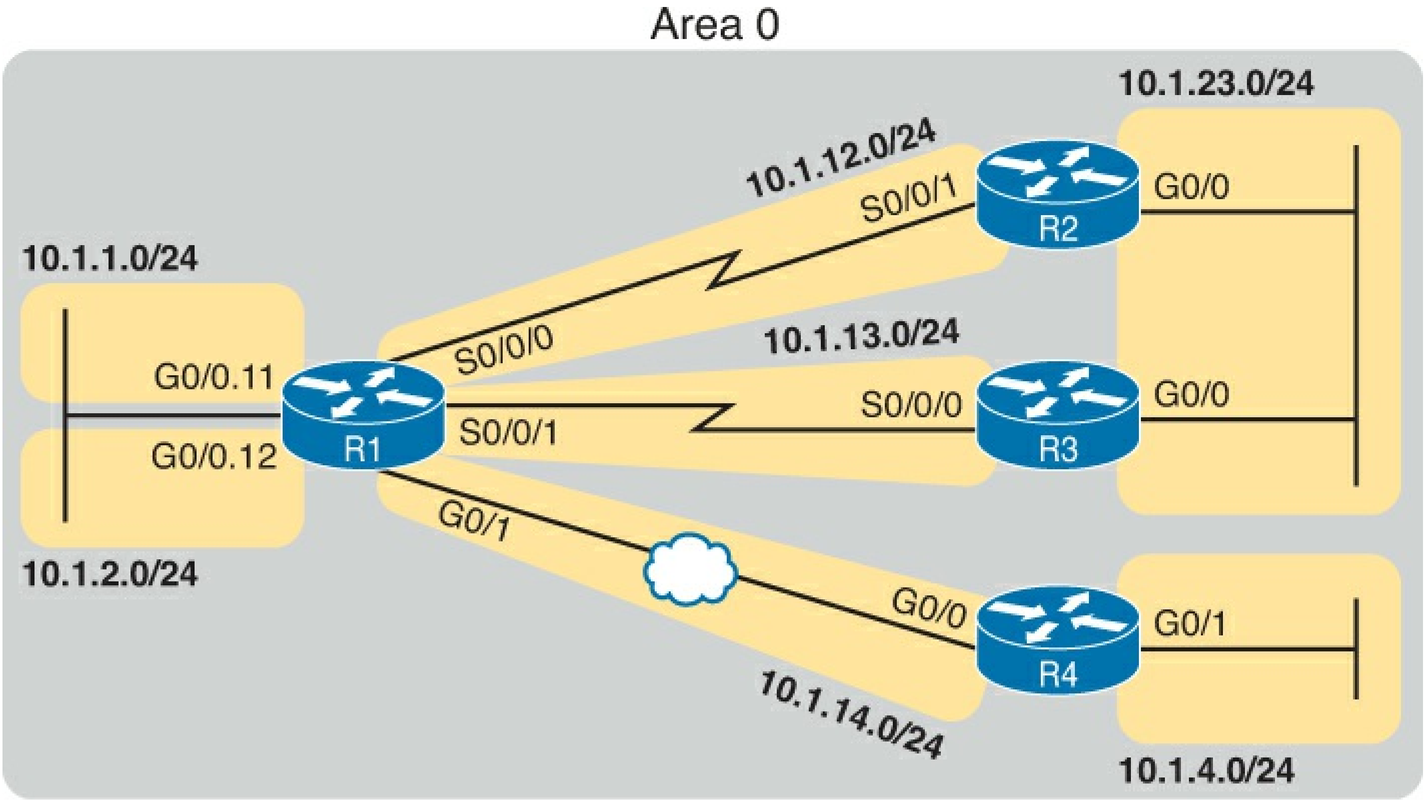

Area 0
10.1.23.0/24
10.1.12.0/24
S0/0/1
R2
G0/0
10.1.1.0/24
S0/0/0
10.1.13.0/24
G0/0.11
R1
S0/0/0
R3
G0/0
G0/0.12
S0/0/1
G0/1
G0/0
R4
G0/1
10.1.2.0/24
10.1.14.0/24
10.1.4.0/24

Figure 8-9. An Enterprise Network with Seven IPv4 Subnets

With the single-area design planned for this small internetwork, the LSDB will contain four router LSAs. Each router creates a router LSA for itself, with its own RID as the LSA identifier. The LSA lists that router's own interfaces, IP address/mask, with pointers to neighbors.

Once all four routers have copies of all four router LSAs, SPF can mathematically analyze the LSAs to create a model. The model looks a lot like the concept drawing in Figure 8-10. Note that the drawing shows each router with an obvious RID value. Each router has pointers that represent each of its interfaces, and because the LSAs identify neighbors, SPF can figure out which interfaces connect to which other routers.

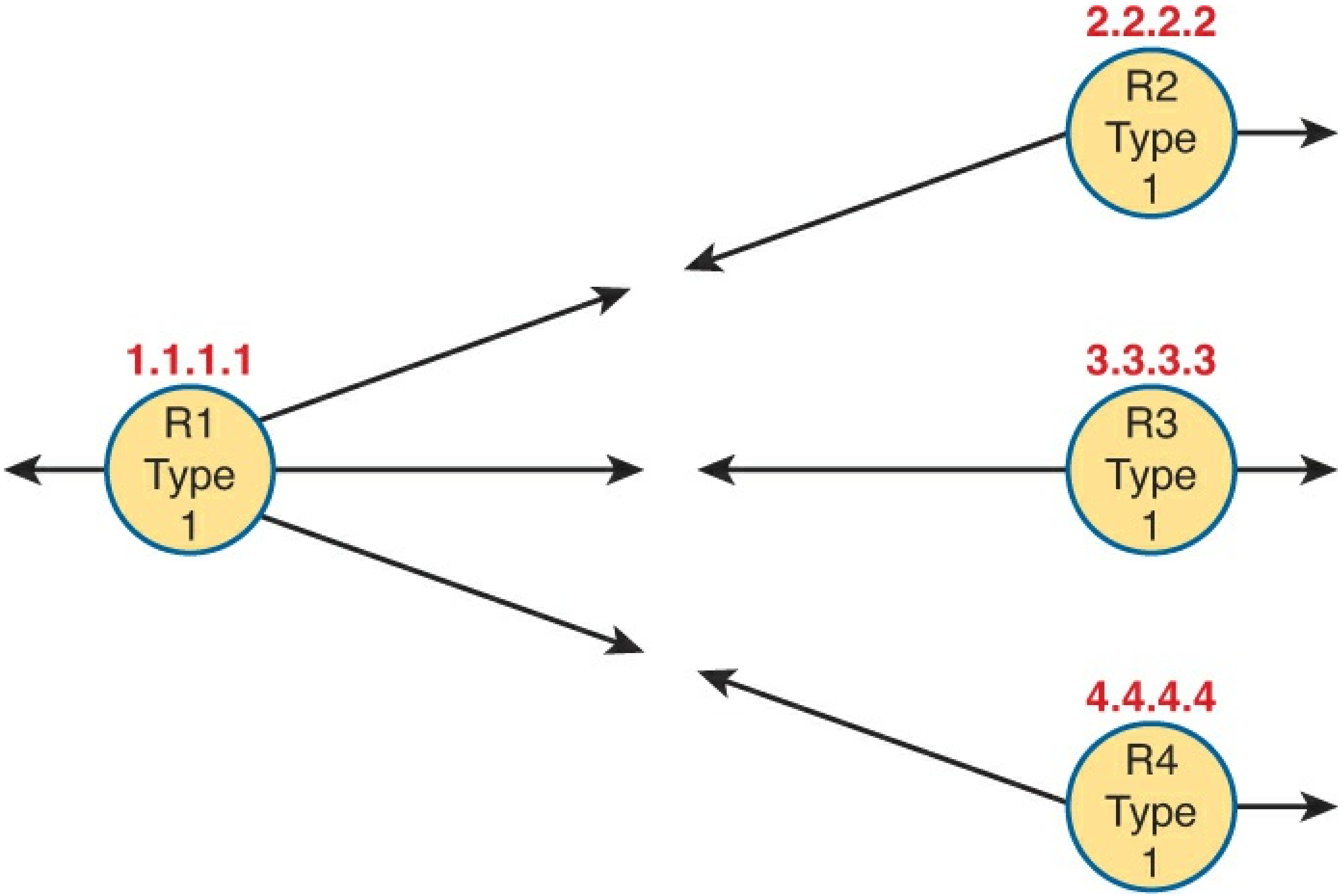

2.2.2.2
R2 Type 1
1.1.1.1
R1 Type 1
3.3.3.3
R3 Type 1
4.4.4.4
R4 Type 1

Figure 8-10. Type 1 LSAs, Assuming a Single-Area Design

Network LSAs Complete the Intra-Area Topology

Whereas router LSAs define most of the intra-area topology, network LSAs define the rest. As it turns out, when OSPF elects a DR on some subnet *and* that DR has at least one neighbor, OSPF treats that subnet as another node in its mathematical model of the network. To represent that network, the DR creates and floods a network (Type 2) LSA for that network (subnet).

For instance, back in Figure 8-9, one Ethernet LAN and one Ethernet WAN exists. The Ethernet LAN between R2 and R3 will elect a DR, and the two routers will become neighbors; so, whichever router is the DR will create a network LSA. Similarly, R1 and R4 connect with an Ethernet WAN, so the DR on that link will create a network LSA.

Figure 8-11 shows the completed version of the intra-area LSAs in area 0 with this design. Note that the router LSAs actually point to the network LSAs when they exist, which lets the SPF processes connect the pieces together.

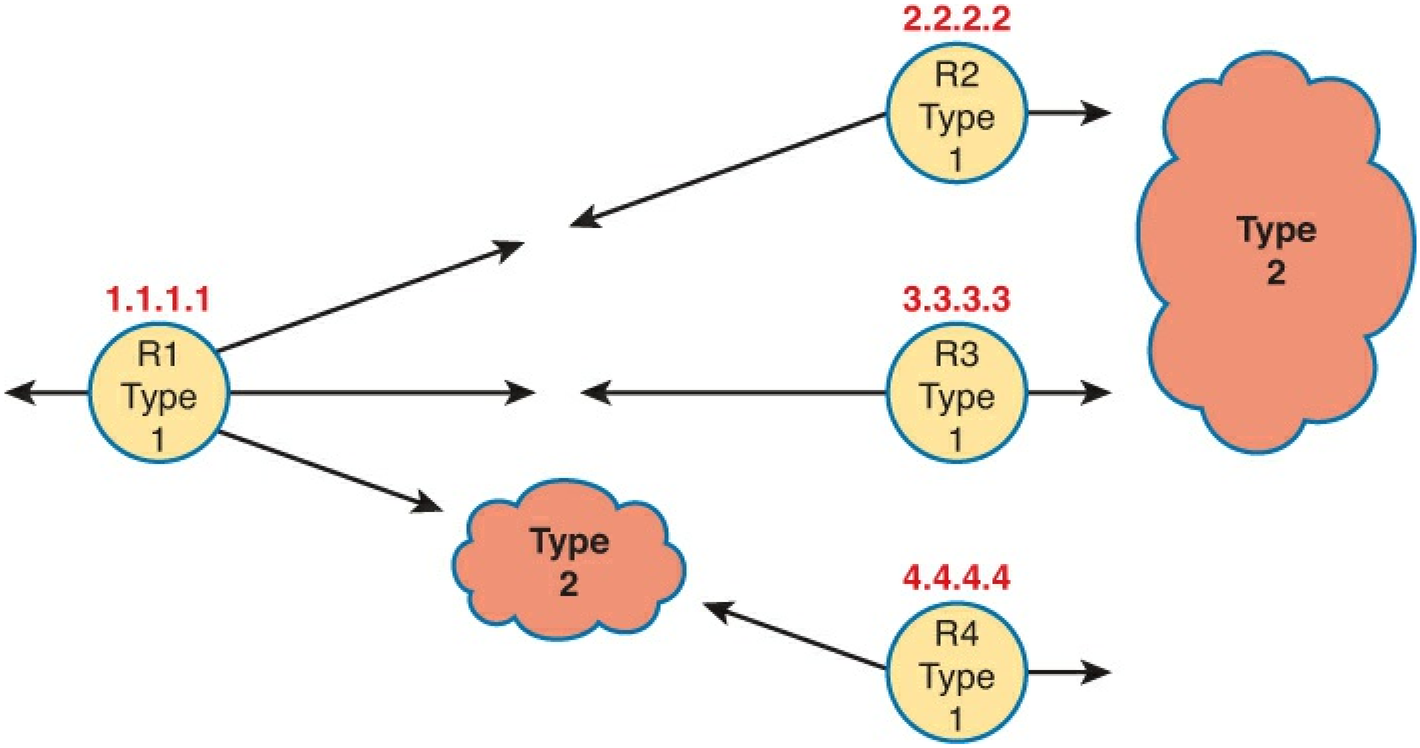


Figure 8-11. Type 1 and Type 2 LSAs in Area 0, Assuming a Single-Area Design

> **Note**
>
> The drawings in the last two figures work a little like a jigsaw puzzle. The SPF algorithm basically solves the jigsaw puzzle, but by looking at all the numbers inside the different LSAs, to see which LSAs fit next to which other LSAs.

Finally, note that in this single-area design example that no summary (Type 3) LSAs exist at all. These LSA represent subnets in other areas, and there are no other areas. The next example shows some summary LSAs.

LSAs in a Multi-Area Design

Migrating from a single-area design to a multi-area design has a couple of effects on LSAs:

- Each area has a smaller number of router and network LSAs.
- The ABRs have a copy of the LSDB for each area to which they connect.
- The ABRs each have a router LSA in each area's LSDB.
- Each area has a need for some summary (Type 3) LSAs to describe subnets in other areas.

Before focusing on these summary LSAs, first work through a new example for a moment. Figure 8-12 begins this new example using the same internetwork topology as Figure 8-9, but now with a multi-area design, with router R1 as the only ABR.

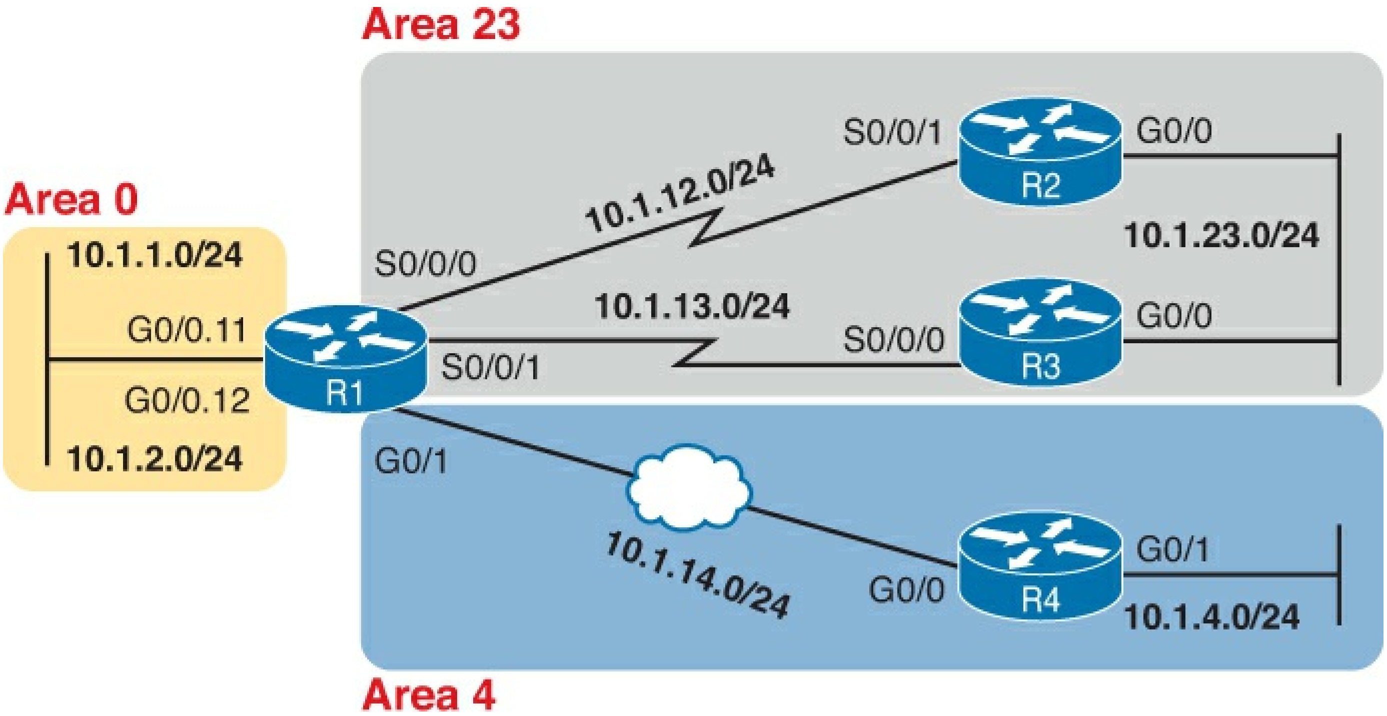

Area 23
Area 0
Area 4
10.1.1.0/24
G0/0.11
G0/0.12
10.1.2.0/24
R1
S0/0/0
S0/0/1
G0/1
10.1.12.0/24
10.1.13.0/24
10.1.14.0/24
S0/0/1
R2
G0/0
10.1.23.0/24
S0/0/0
R3
G0/0
G0/0
R4
G0/1
10.1.4.0/24

Figure 8-12. A Multi-Area Design for the Same Internetwork as Figure 8-9

Next, consider what router and network LSAs should be in the area 4 LSDB. Remember, inside an area, the LSDB should have router LSAs for routers inside the area, and network LSAs for certain networks inside the area (those with a DR that has at least one neighbor). So, the area 4 LSDB will include two router LSAs (for R1 and R4), plus one network LSA, for the network between R1 and R4, as shown in Figure 8-13.

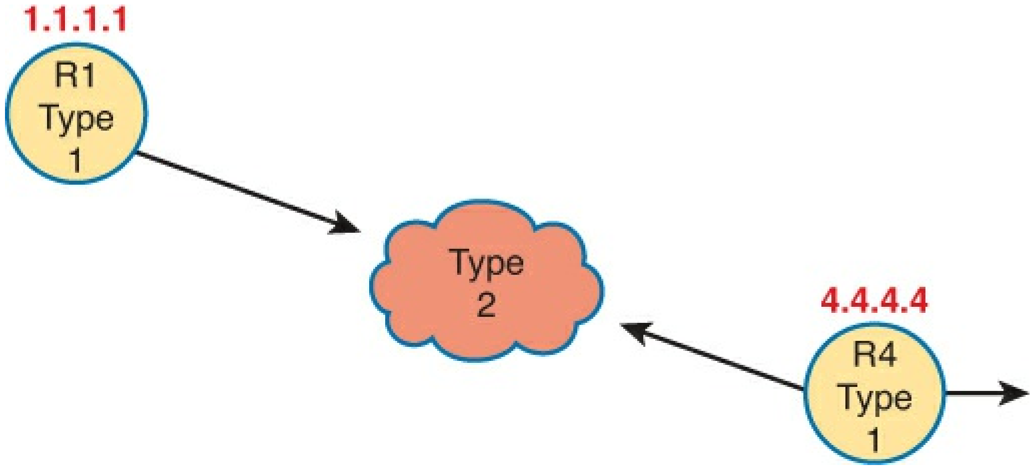

1.1.1.1
R1 Type 1
Type 2
4.4.4.4
R4 Type 1

Figure 8-13. Router and Network LSAs in Area 4 Only, Assuming the Multi-Area Design in Figure 8-12

Now focus on the subnets in the entire internetwork for a moment. Breaking it down by area, we have the following:

- Three subnets in area 23
- Two subnets in area 4
- Two subnets in area 0

The routers inside area 4 need to know about the five subnets outside area 4, and to do that, the ABR (R1) advertises summary LSAs into area 4.

Summary (Type 3) LSAs describes a subnet that sits in another area. First, it has to list the subnet ID and mask to identify the specific subnet. The LSA also lists the RID of the ABR that creates and advertises the summary LSA into the area. By identifying the ABR, from a topology perspective, these subnets appear to be connected to the ABR. In this new example, ABR R1 creates and floods the five Summary LSAs shown in the upper left of Figure 8-14.

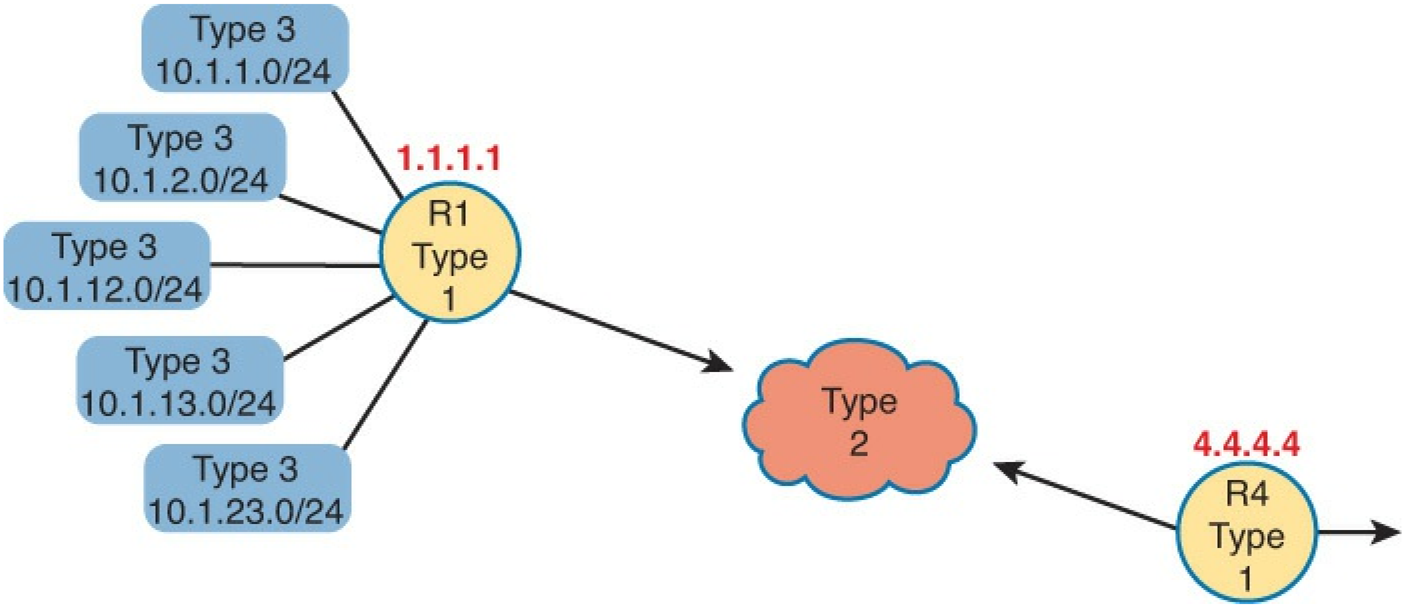


Figure 8-14. Type 3 LSAs Injected by ABR R1 into the Area 4 LSDB

> **Note**
>
> Note that the OSPF summary LSA does not mean that the router is performing route summarization, which is the process of taking multiple routes, for multiple subnets, and advertising them as one route for a larger subnet.

Calculating the Best Routes with SPF

As you can see from these LSAs, they contain useful information, but they do not contain the specific information that a router needs to add to its IPv4 routing table. In other words, a router cannot just copy information from the LSDB into a route in the IPv4 routing table. Instead, the router must do the SPF math, choose the best route, and add a route: a route with a subnet number and mask, an outgoing interface, and a next-hop router IP address.

Although engineers do not need to know the details of how SPF does the math, they do need to know how to predict which routes SPF will choose as the best route. The SPF algorithm calculates all the routes for a subnet—that is, all possible routes from the router to the destination subnet. If more than one route exists, the router compares the metrics, picking the best (lowest) metric route to add to the routing table. Although the SPF math can be complex, engineers with a network diagram, router status information, and simple addition can calculate the metric for each route, predicting what SPF will choose.

Once SPF has identified a route, it calculates the metric for a route as follows:

Key Topic

The sum of the OSPF interface costs for all outgoing interfaces in the route

Figure 8-15 shows an example with three possible routes from R1 to Subnet X (172.16.3.0/24) at the bottom of the figure.

Key Topic

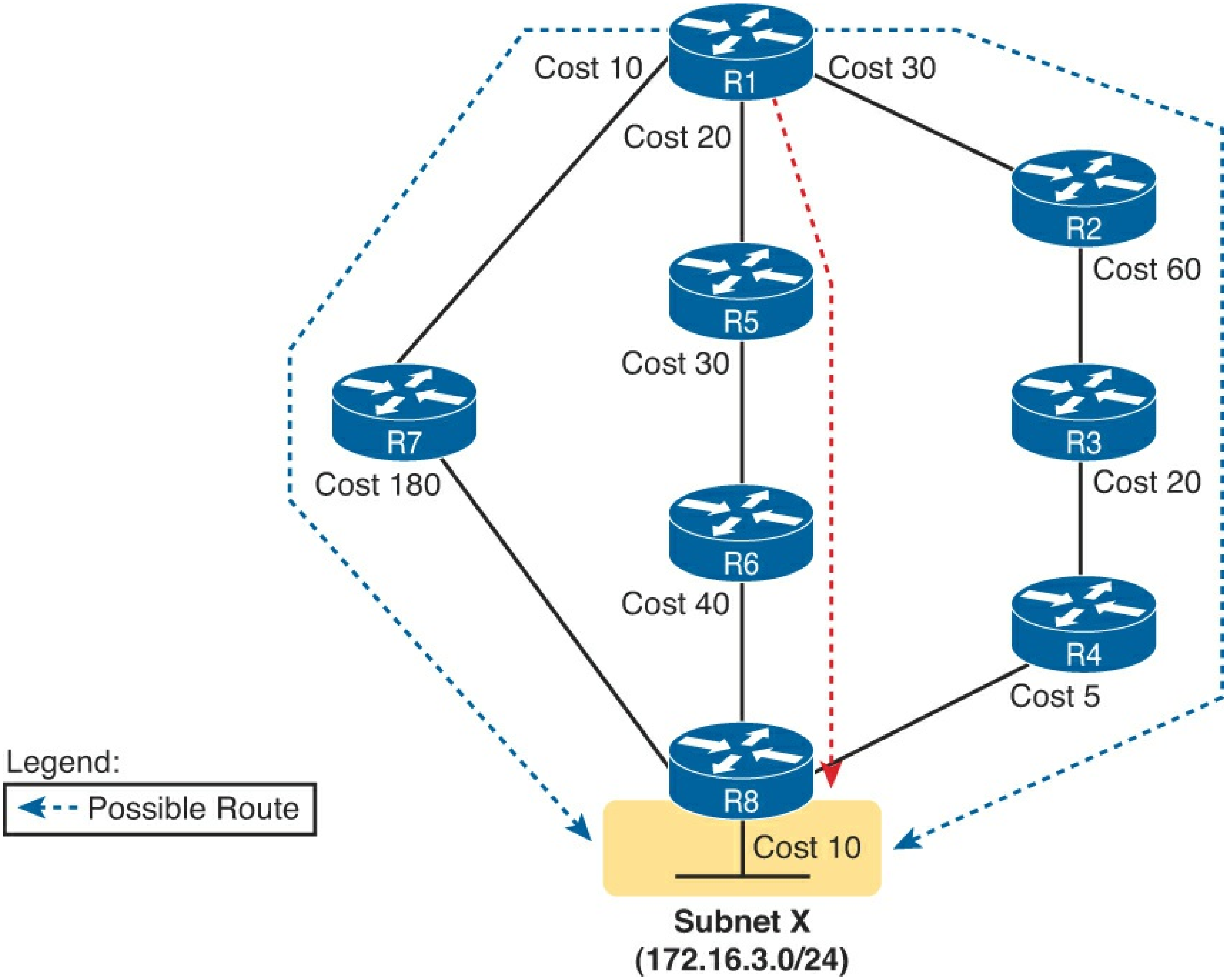

Cost 10
R1
Cost 30
Cost 20
R2
Cost 60
R5
Cost 30
R7
R3
Cost 180
Cost 20
R6
Cost 40
R4
Cost 5
Legend:
Possible Route
R8
Cost 10
Subnet X
(172.16.3.0/24)

Figure 8-15. SPF Tree to Find R1's Route to 172.16.3.0/24

Note

OSPF considers the costs of the outgoing interfaces (only) in each route. It does not add the cost for incoming interfaces in the route.

Table 8-5 lists the three routes shown in Figure 8-15, with their cumulative costs, showing that R1's best route to 172.16.3.0/24 starts by going through R5.

Table 8-5. Comparing R1's Three Alternatives for the Route to 172.16.3.0/24

Route	Location in Figure 8-15	Cumulative Cost
R1–R7–R8	Left	10 + 180 + 10 = 200
R1–R5–R6–R8	Middle	20 + 30 + 40 + 10 = 100
R1–R2–R3–R4–R8	Right	30 + 60 + 20 + 5 + 10 = 125

As a result of the SPF algorithm's analysis of the LSDB, R1 adds a route to subnet 172.16.3.0/24 to its routing table, with the next-hop router of R5.

In real OSPF networks, an engineer can do the same process by knowing the OSPF cost for each interface. Armed with a network diagram, the engineer can examine all routes, add the costs, and predict the metric for each route.

Note

OSPF calculates costs using different processes depending on the area design. The example surrounding Figure 8-15 best matches OSPF's logic when using a single-area design.

Administrative Distance

OSPF can choose the best route for each subnet based on OSPF's metric, as discussed in the previous page or two of this chapter. However, IOS must also be able to choose the best route to reach a subnet when the router knows of routes from different sources. To make such a choice, routers use a concept called administrative distance (AD).

First, think about a common case, in which all the routers use OSPF, and only OSPF, as the one routing protocol for IPv4. A router learns routes with OSPF, but it also learns connected routes. It may also have some **ip route** commands that define static IPv4 routes. It could be that one router knows about a connected, static, and OSPF route for a single subnet. How does a router choose which to use?

Any time a router must choose between competing connected, static, and OSPF routes, the router uses the connected route by default. Why? Although it might appear to be just good common sense, the router actually chooses the connected route because of its lower (better) AD of 0. Static routes have an AD of 1 by default, and OSPF routes have an AD of 110 by default.

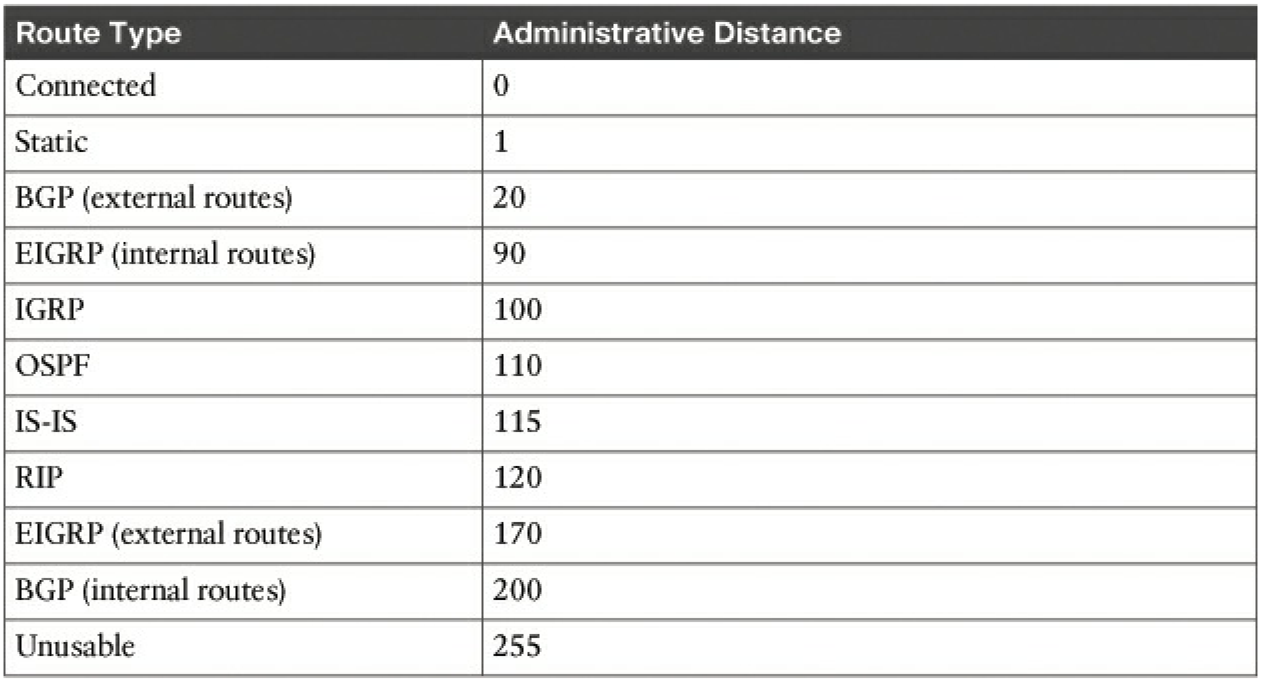
Taking the idea a step further, in some cases, a company needs to use multiple routing protocols. For instance, if two companies connect their networks so that they can exchange information, they need to exchange some routing information. If one company uses OSPF, and the other uses EIGRP on at least one router, both OSPF and Enhanced Interior Gateway Routing Protocol (EIGRP) must be used. Then, that router can take routes learned by OSPF and advertise them into EIGRP, and vice versa, through a process called *route redistribution*.

Depending on the network topology, one router might learn a route to a subnet with both OSPF and with EIGRP. In this case, because each routing protocol's metric is based on different information, IOS cannot compare the metrics. In this case, IOS again chooses the best route based on the administrative distance.

The AD values are configured on a single router and are not exchanged with other routers. Table 8-6 lists the various sources of routing information, along with the default ADs.

Key Topic

Table 8-6. Default Administrative Distances



Route Type	Administrative Distance
Connected	0
Static	1
BGP (external routes)	20
EIGRP (internal routes)	90
IGRP	100
OSPF	110
IS-IS	115
RIP	120
EIGRP (external routes)	170
BGP (internal routes)	200
Unusable	255

Note

The **show ip route** command lists each route's administrative distance as the first of the two numbers inside the brackets. The second number in brackets is the metric.

The table shows the default administrative distance values, but IOS can be configured to change the AD of a particular routing protocol or even a single route. For instance, the command **distance 80**, from OSPF configuration mode, sets the AD of all OSPF-learned routes on that router to an AD value of 80.

OSPF Configuration and Verification

Now that you have a big dose of OSPF theory, this second half of the chapter shows how to make OSPF work, with multi-area designs, and with influencing route selection by changing OSPF interface costs. Then the verification topics show the specifics of these features, plus some of the OSPF and LSA features discussed in the first half of the chapter.

OSPFv2 Configuration Overview

First, for those of you who might not remember the OSPF configuration from the ICND1 book, take a few moments to review the configuration. This checklist lists the commands, with some commentary about the **network** command to follow. Also, note that the upcoming configuration example uses these same commands.

Key Topic

Step 1. Enter OSPF configuration mode for a particular OSPF process using the **router ospf** *process-id* global command.

Step 2. (Optional) Configure the OSPF router ID by

- **A.** Configuring the **router-id** *id-value* router subcommand
- **B.** Configuring an IP address on a loopback interface (chooses the highest IP address of all working loopbacks)
- **C.** Relying on an interface IP address (chooses the highest IP address of all working nonloopbacks)

Step 3. Configure one or more **network** *ip-address wildcard-mask* **area** *area-id* router subcommands, with any matched interfaces being enabled for the OSPF process and being assigned to the listed area.

Step 4. (Optional) Configure any OSPF interfaces as passive if no neighbors can or should be discovered on the interface, using the **passive-interface** *type number* interface subcommand.

Of these commands, the only one that causes much trouble is the OSPF **network** command. The OSPF **network** command compares the first parameter in the command to each interface IP address on the local router, trying to find a match. However, rather than comparing the entire number in the **network** command to the entire IPv4 address on the interface, the router can compare a subset of the octets, based on the access control list (ACL)-style wildcard mask.

For perspective, this list shows several **network** commands, with a description of what IP addresses the command would match:

network 10.1.1.1 0.0.0.0 area 0: Matches an interface with exactly address 10.1.1.1

network 10.1.1.0 0.0.0.255 area 0: Matches any interface whose address begins with 10.1.1

network 10.0.0.0 0.255.255.255 area 0: Matches any interface whose address begins with 10

network 0.0.0.0 255.255.255.255 area 0: Matches any interface that has some IP address configured

Basically, a wildcard mask value of 0 in an octet tells IOS to compare to see whether the numbers match, and a value of 255 tells IOS to ignore that octet when comparing the numbers.

Multi-Area OSPFv2 Configuration Example

Before looking at the multi-area configuration, bear with me for a brief tangent about the exam topics for OSPF. Frankly, the OSPF exam topics (at the time of publication) skirt around the dividing line of whether you need to know how to configure multi-area OSPF (both OSPFv2 and OSPFv3). The configuration-oriented exam topics clearly imply single-area configuration only, while the troubleshooting topics may imply that you need knowledge of multi-area configuration. The good news is this: When you understand multi-area concepts and single-area configuration, adding multi-area configuration is incredibly simple. So, this topic shows the multi-area details, just in case you need them for the exam.

Next, the text shows a configuration example for a multi-area OSPF design, based on the same three-area design shown earlier as Figure 8-12. Figure 8-16 repeats the internetwork topology and subnet IDs, and Figure 8-17 shows the area design. Note that Figure 8-16 lists the last octet of each router's IPv4 address near each interface, rather than the entire IPv4 address, to reduce clutter.

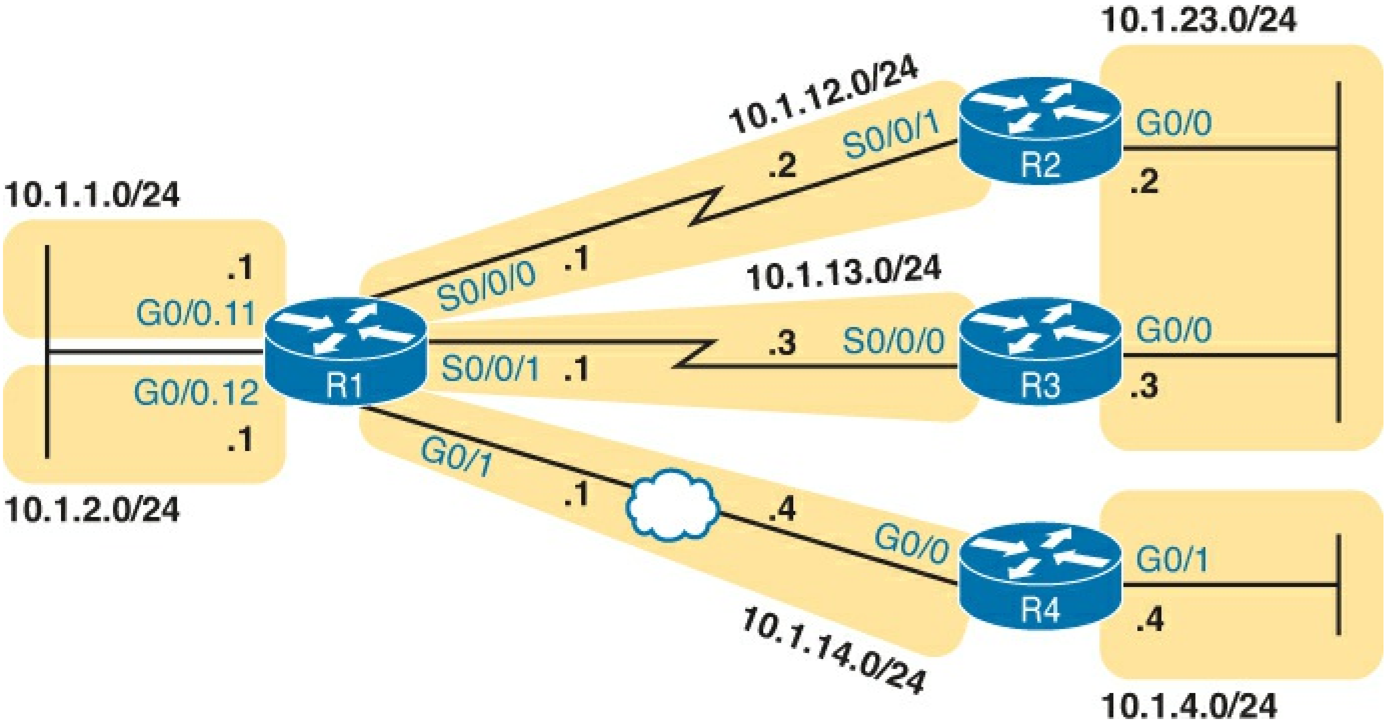


Figure 8-16. Subnets for a Multi-Area OSPF Configuration Example

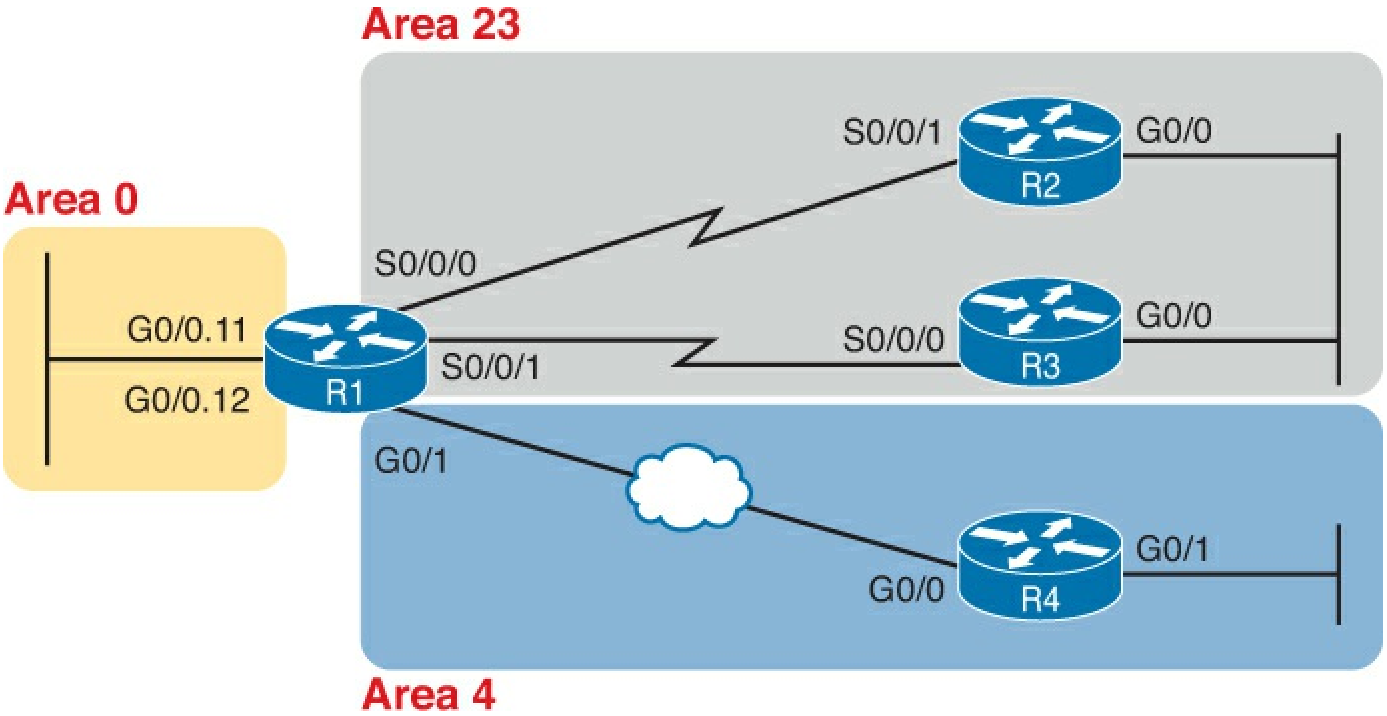


Figure 8-17. Area Design for an Example Multi-Area OSPF Configuration

The configurations on the four routers in this example also serve as a review for ICND1-level OSPF configuration. To that end, for no other reason than to show a variety of options, the configurations show several ways to set the OSPF RID and several different wildcard masks on OSPF **network** commands. It also shows the use of passive interfaces where no other OSPF routers should exist off an interface.

Single-Area Configurations

Example 8-1 begins the configuration example by showing the OSPF and IP address configuration on R2. Note that R2 acts as an internal router in area 23, meaning that the configuration will refer to only one area (23). The configuration sets R2's RID to 2.2.2.2 directly with the **router-id** command. And, because R2 should find neighbors on both its two interfaces, neither can reasonably be made passive, so R2's configuration lists no passive interfaces.

Example 8-1. OSPF Configuration on R2, Placing Two Interfaces into Area 23

Click here to view code image

```
interface GigabitEthernet0/0
ip address 10.1.23.2 255.255.255.0
!
interface serial 0/0/1
ip address 10.1.12.2 255.255.255.0
!
router ospf 1
network 10.0.0.0 0.255.255.255 area 23
router-id 2.2.2.2
```

Example 8-2 continues reviewing commands originally introduced in ICND1, showing the configuration for both R3 and R4. R3 puts both its interfaces into area 23, per its **network** command, sets its RID to 3.3.3.3 by using a loopback interface, and like R2, cannot make either of its interfaces passive. The R4 configuration is somewhat different, with both interfaces placed into area 4, setting its RID based on a nonloopback interface (G0/0, for OSPF RID 10.1.14.4), and making R4's G0/1 interface passive, because no other OSPF routers sit on that link.

Example 8-2. OSPF Single-Area Configuration on R3 and R4

Click here to view code image

```
! First, on R3
interface gigabitEthernet0/0
ip address 10.1.23.3 255.255.255.0
!
interface serial 0/0/0
ip address 10.1.13.3 255.255.255.0
```

```
!
interface loopback 0
ip address 3.3.3.3 255.255.255.0
!
router ospf 1
network 10.0.0.0 0.255.255.255 area 23
```

```
! Next, on R4
interface GigabitEthernet0/0
description R4 will use this interface for its OSPF RID
ip address 10.1.14.4 255.255.255.0
!
interface GigabitEthernet0/1
ip address 10.1.4.4 255.255.255.0
!
router ospf 1
network 10.0.0.0 0.255.255.255 area 4
passive-interface gigabitethernet0/1
```

Multi-Area Configuration

So far, the examples have not actually shown a multi-area configuration. Routers R2, R3, and R4 each sit inside a single area, as internal OSPF routers, so their configuration lists only a single area. None of them use a multi-area configuration.

The only router that has a multi-area config is an ABR, by virtue of the configuration referring to more than one area. In this design (as shown in Figure 8-17), only router R1 acts as an ABR, with interfaces in three different areas. Example 8-3 shows R1’s OSPF configuration. Note that the configuration does not state anything about R1 being an ABR; instead, it uses multiple **network** commands, some placing interfaces into area 0, some into area 23, and some into area 4.

Key Topic

Example 8-3. OSPF Multi-Area Configuration on Router R1

Click here to view code image

```
interface GigabitEthernet0/0.11
encapsulation dot1q 11
ip address 10.1.1.1 255.255.255.0
!
interface GigabitEthernet0/0.12
encapsulation dot1q 12
ip address 10.1.2.1 255.255.255.0
!
interface GigabitEthernet0/1
ip address 10.1.14.1 255.255.255.0
!
interface serial 0/0/0
ip address 10.1.12.1 255.255.255.0
!
interface serial 0/0/1
ip address 10.1.13.1 255.255.255.0
!
router ospf 1
network 10.1.1.1 0.0.0.0 area 0
network 10.1.2.1 0.0.0.0 area 0
network 10.1.12.1 0.0.0.0 area 23
network 10.1.13.1 0.0.0.0 area 23
network 10.1.14.1 0.0.0.0 area 4
router-id 1.1.1.1
passive-interface gigabitethernet0/0.11
passive-interface gigabitethernet0/0.12
```

Focus on the highlighted **network** commands in the example. All five commands happen to use a wildcard mask of 0.0.0.0, so that each command requires a specific match of the listed IP address. If you compare these **network** commands to the various interfaces, you can see that the configuration enables OSPF, for area 0, on subinterfaces G0/0.11 and G0/0.12, area 23 for the two serial interfaces, and area 4 for R1's G0/1 interface.

> **Note**
>
> Many networks make a habit of using a 0.0.0.0 wildcard mask on OSPF **network** commands, requiring an exact match of each interface IP address, as shown in Example 8-3. This style of configuration makes it more obvious exactly which interfaces match which **network** command.

Finally, note that R1's configuration also sets its RID directly and makes its two LAN subinterfaces passive.

So, what's the big difference between single area and multi-area OSPF configuration? Practically nothing. The only difference is that with multi-area the ABR's **network** commands list different areas.

Verifying the Multi-Area Configuration

The next few pages look at how to verify a few of the new OSPF features introduced in this chapter. For a more thorough verification of OSPF, use all the commands suggested in the review figure (Figure 8-1) at the beginning of this chapter. This section looks at the following new topics:

- Verifying the ABR interfaces are in the correct (multiple) areas
- Finding which router is DR and BDR on multiaccess links
- Confirming the correct number of different types of LSAs exist in each area
- Displaying IPv6 routes

Verifying the Correct Areas on Each Interface on an ABR

The easiest place to make a configuration oversight with a multi-area configuration is to place an interface into the wrong OSPF area. Several commands mention the OSPF area. The **show ip protocols** command basically relists the OSPF **network** configuration commands, which indirectly identify the interfaces and areas. Also, the **show ip ospf interface** and **show ip ospf interface brief** commands directly show the area configured for an interface; Example 8-4 shows an example of the briefer version of these commands.

Example 8-4. Listing the OSPF-enabled Interfaces and the Matching OSPF Areas

Click here to view code image

```
R1# show ip ospf interface brief
Interface PID Area IP Address/Mask Cost State Nbrs F/C
Gi0/0.12 1 0 10.1.2.1/24 1 DR 0/0
Gi0/0.11 1 0 10.1.1.1/24 1 DR 0/0
Gi0/1 1 4 10.1.14.1/24 1 BDR 1/1
Se0/0/1 1 23 10.1.13.1/24 64 P2P 1/1
Se0/0/0 1 23 10.1.12.1/24 64 P2P 1/1
```

In the output, to correlate the areas, just look at the Interface in the first column, and the area in the third column. Also, for this example, double-check this information with Figures 8-16 and 8-17 to confirm that the configuration matches the design.

Verifying Which Router Is DR and BDR

Several **show** commands identify the DR and BDR in some way, as well. In fact, the **show ip ospf interface brief** command output, just listed in Example 8-4, lists the local router's State, showing that R1 is DR on two subinterfaces and BDR on its G0/1 interface.

Example 8-5 shows two other examples that identify the DR and BDR, but with a twist. The **show ip ospf interface** command lists detailed output about OSPF settings, per interface. Those details include the RID and interface address of the DR and BDR. At the same time, the **show ip ospf neighbor** command lists shorthand information about the neighbor's DR or BDR role as well; this command does not say anything about the local router's role. Example 8-5 shows examples of both commands.

Example 8-5. Discovering the DR and BDR on the R1-R4 Ethernet (from R4)

Click here to view code image

```
R4# show ip ospf interface gigabitEthernet 0/0
GigabitEthernet0/0 is up, line protocol is up
Internet Address 10.1.14.4/24, Area 4, Attached via Network Statement
Process ID 1, Router ID 10.1.14.4, Network Type BROADCAST, Cost: 1
Topology-MTID Cost Disabled Shutdown Topology Name
0 1 no no Base
```

```
Transmit Delay is 1 sec, State DR, Priority 1
Designated Router (ID) 10.1.14.4, Interface address 10.1.14.4
Backup Designated router (ID) 1.1.1.1, Interface address 10.1.14.1
!
! Lines omitted for brevity
R4# show ip ospf neighbor

Neighbor ID Pri State Dead Time Address Interface
1.1.1.1 1 FULL/BDR 00:00:33 10.1.14.1 GigabitEthernet0/0
```

First, focus on the highlighted lines from the **show ip ospf interface** command output. It lists the DR as RID 10.1.14.4, which happens to be R4. It also lists the BDR as 1.1.1.1, which is R1. (As a reminder, while the earlier conceptual figures showed R4 with an RID of 4.4.4.4, the configuration for R4, in Example 8-2, results in an RID of 10.1.14.4. That configuration did not use the **router-id** configuration command and did not use a loopback interface on R4.)

The end of the example shows the **show ip ospf neighbor** command on R4, listing R4's single neighbor, with Neighbor RID 1.1.1.1 (R1). The command lists R4's concept of its neighbor state with neighbor 1.1.1.1 (R1), with the current state listed as FULL/BDR. The FULL state means that R4 has fully exchanged its LSDB with R1. The BDR means that the neighbor (R1) is acting as the BDR, implying that R4 (the only other router on this link) is acting as the DR.

Verifying the Number and Type of LSAs

Earlier in this chapter, the "Link-State Advertisements" section discussed LSA Types 1, 2, and 3 in some depth. The multi-area configuration example uses the exact same area design as the earlier multi-area LSA examples, so a quick check of the OSPF LSDB should confirm the concepts discussed earlier in the chapter.

Figure 8-14 showed how area 4's LSDB should have two router LSAs, one network LSA, and five summary LSAs. The **show ip ospf database** command in Example 8-6, taken from router R4, shows R4's view of the area 4 LSDB.

Example 8-6. Verifying the Number and Type of LSAs in Area 4

Click here to view code image

```
R4# show ip ospf database

OSPF Router with ID (10.1.14.4) (Process ID 1)

Router Link States (Area 4)

Link ID ADV Router Age Seq# Checksum Link count
1.1.1.1 1.1.1.1 1252 0x80000015 0x00AE30 1
10.1.14.4 10.1.14.4 1453 0x80000015 0x00A2E7 2

Net Link States (Area 4)

Link ID ADV Router Age Seq# Checksum
10.1.14.4 10.1.14.4 1453 0x80000014 0x007259

Summary Net Link States (Area 4)

Link ID ADV Router Age Seq# Checksum
10.1.1.0 1.1.1.1 1493 0x80000014 0x00B563
10.1.2.0 1.1.1.1 1493 0x80000014 0x00AA6D
10.1.12.0 1.1.1.1 1493 0x80000014 0x00B41A
10.1.13.0 1.1.1.1 1493 0x80000014 0x00A924
10.1.23.0 1.1.1.1 1493 0x80000014 0x00457D
```

Note that the example highlights the three heading lines for the three LSA types, plus in the Router LSA area, the highlights focus on the link IDs for the router LSAs. The Router LSA section highlights the RIDs that identify the two router LSAs: the router LSA for R1 (RID 1.1.1.1) and for R4 (RID 10.1.14.4). If you look inside the Net (Network) LSAs area, you will find a single LSA listed, with ID 10.1.14.4. Finally, the last section lists the five summary LSAs inside area 4.

> **Note**
>
> The terms *neighbor table*, *topology table*, and *routing table* are sometimes used to refer to three of OSPFv2 key lists. The term neighbor table refers to the list of neighbors, and the term topology table refers to the topology database, as displayed in Example 8-6.

Verifying OSPF Routes

Finally, all this OSPF theory and all the **show** commands do not matter if the routers do not learn IPv4 routes. To verify the routes, Example 8-7 shows R4's IPv4 routing table.

Example 8-7. Verifying OSPF Routes on Router R1

Click here to view code image

```
R4# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
E1 - OSPF external type 1, E2 - OSPF external type 2
i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
ia - IS-IS inter area, * - candidate default, U - per-user static route
o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
+ - replicated route, % - next hop override

10.0.0.0/8 is variably subnetted, 9 subnets, 2 masks
O IA 10.1.1.0/24 [110/2] via 10.1.14.1, 11:04:43, GigabitEthernet0/0
O IA 10.1.2.0/24 [110/2] via 10.1.14.1, 11:04:43, GigabitEthernet0/0
C 10.1.4.0/24 is directly connected, GigabitEthernet0/1
L 10.1.4.4/32 is directly connected, GigabitEthernet0/1
O IA 10.1.12.0/24 [110/65] via 10.1.14.1, 11:04:43, GigabitEthernet0/0
O IA 10.1.13.0/24 [110/65] via 10.1.14.1, 11:04:43, GigabitEthernet0/0
C 10.1.14.0/24 is directly connected, GigabitEthernet0/0
L 10.1.14.4/32 is directly connected, GigabitEthernet0/0
O IA 10.1.23.0/24 [110/66] via 10.1.14.1, 11:04:43, GigabitEthernet0/0
```

This example shows a couple of new codes that are particularly interesting for OSPF. As usual, a single character on the left identifies the source of the route, with O meaning OSPF. In addition, IOS notes any interarea routes with an IA code as well. (The example does not list any intra-area OSPF routes, but these routes would simply omit the IA code.) Also, note that R4 has routes to all seven subnets in this example: two connected routes and five interarea OSPF routes.

OSPF Metrics (Cost)

Earlier, the "Calculating the Best Routes with SPF" section discussed how SPF calculates the metric for each route, choosing the route with the best metric for each destination subnet. OSPF routers can influence that choice by changing the OSPF interface cost on any and all interfaces.

Cisco routers allow two different ways to change the OSPF interface cost. The one straightforward way is to set the cost directly, with an interface subcommand: **ip ospf cost** *x*. The other method is to let IOS choose default costs, based on a formula, but to change the inputs to the formula. This second method requires a little more thought and care and is the focus of this next topic.

Setting the Cost Based on Interface Bandwidth

The default OSPF cost values can actually cause a little confusion, for a couple of reasons. So, to get through some of the potential confusion, this section begins with some examples.

First, IOS uses the following formula to choose an interface's OSPF cost. IOS puts the interface's bandwidth in the denominator, and a settable OSPF value called the *reference bandwidth* in the numerator:

Reference_bandwidth / Interface_bandwidth

With this formula, a higher interface bandwidth is better. The higher (faster) the interface bandwidth, the lower the calculated OSPF cost for the interface. The lower the interface cost, the lower the metric for routes using that interface, and the more likely the interface is used in a route chosen by SPF.

Now, for some examples. Assume a default reference bandwidth, set to 100,000 Kbps. Assume defaults for interface bandwidth on serial, Ethernet, and Fast Ethernet interfaces, as shown in the output of the **show interfaces** command, respectively, of 1544 Kbps, 10,000 Kbps (meaning 10 Mbps), and 100,000 Kbps (meaning 100 Mbps). Table 8-7 shows the results of how IOS calculates the OSPF cost for some interface examples.

Table 8-7. OSPF Cost Calculation Examples with Default Bandwidth Settings

Interface	Interface Default Bandwidth (Kbps)	Formula (Kbps)	OSPF Cost
Serial	1544 Kbps	100,000/1544	64
Ethernet	10,000 Kbps	100,000/10,000	10
Fast Ethernet	100,000 Kbps	100,000/100,000	1

To change the OSPF cost on these interfaces, the engineer simply needs to use the **bandwidth** *speed* interface subcommand to set the bandwidth on an interface. The interface bandwidth does not change the Layer 1 transmission speed at all; instead, it is used for other purposes, including routing protocol metric calculations. For instance, if you add the **bandwidth 10000** command to a serial interface, with a default reference bandwidth, the serial interface's OSPF cost could be calculated as 100,000 / 10,000 = 10.

Example 8-8 shows the cost settings on R1's OSPF interfaces, all based on default OSPF (reference bandwidth) and default interface bandwidth settings.

Example 8-8. Confirming OSPF Interface Costs

Click here to view code image

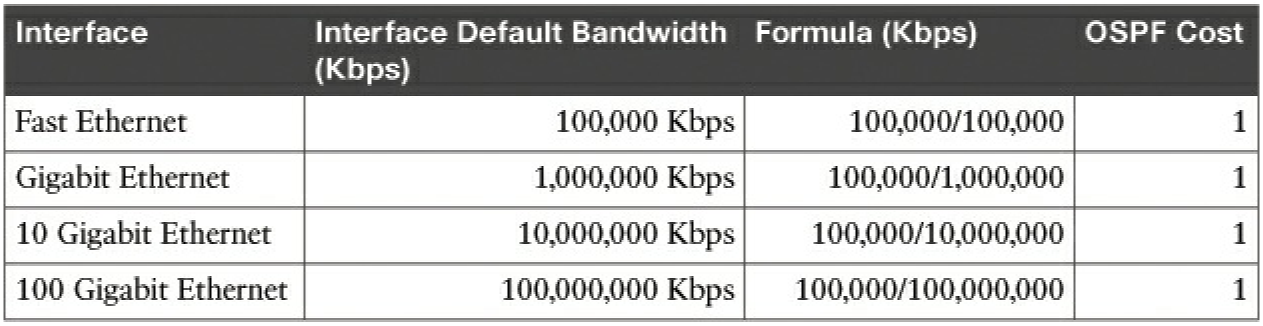
```
R1# show ip ospf interface brief
Interface PID Area IP Address/Mask Cost State Nbrs F/C
Gi0/0.12 1 0 10.1.2.1/24 1 DR 0/0
Gi0/0.11 1 0 10.1.1.1/24 1 DR 0/0
Gi0/1 1 4 10.1.14.1/24 1 BDR 1/1
Se0/0/1 1 23 10.1.13.1/24 64 P2P 1/1
Se0/0/0 1 23 10.1.12.1/24 64 P2P 1/1
```

Note that if the calculation of the default metric results in a fraction, OSPF rounds down to the nearest integer. For instance, the example shows the cost for interface S0/0/0 as 64. The calculation used the default serial interface bandwidth of 1.544 Mbps, with reference bandwidth 100 (Mbps), with the 100/1.544 calculation resulting in 64.7668394. OSPF rounds down to 64.

The Need for a Higher Reference Bandwidth

This default calculation works nicely as long as the fastest link in the network runs at 100 Mbps. The default reference bandwidth is set to 100, meaning 100 Mbps, the equivalent of 100,000 Kbps. As a result, with default settings, faster router interfaces end up with the same OSPF cost, as shown in Table 8-8, because the lowest allowed OSPF cost is 1.

Table 8-8. Faster Interfaces with Equal OSPF Costs



Interface	Interface Default Bandwidth (Kbps)	Formula (Kbps)	OSPF Cost
Fast Ethernet	100,000 Kbps	100,000/100,000	1
Gigabit Ethernet	1,000,000 Kbps	100,000/1,000,000	1
10 Gigabit Ethernet	10,000,000 Kbps	100,000/10,000,000	1
100 Gigabit Ethernet	100,000,000 Kbps	100,000/100,000,000	1

To avoid this issue, and change the default cost calculation, you can change the reference bandwidth with the **auto-cost reference-bandwidth** *speed* OSPF mode subcommand. This command sets a value in a unit of megabits per second (Mbps). To avoid the issue shown in Table 8-8, set the reference bandwidth value to match fastest link speed in the network. For instance, **auto-cost reference-bandwidth 10000** accommodates links up to 10 Gbps in speed.

> **Note**
>
> Cisco recommends making the OSPF reference bandwidth setting the same on all OSPF routers in an enterprise network.

For convenient study, the following list summarizes the rules for how a router sets its OSPF interface costs:

Key Topic

1. Set the cost explicitly, using the **ip ospf cost** *x* interface subcommand, to a value between 1 and 65,535, inclusive.
2. Change the interface bandwidth with the **bandwidth** *speed* command, with speed being a number in kilobits per second (Kbps).
3. Change the reference bandwidth, using router OSPF subcommand **auto-cost reference-bandwidth** *ref-bw*, with a unit of megabits per second (Mbps).

OSPF Load Balancing

When a router uses SPF to calculate the metric for each of several routes to reach one subnet, one route may have the lowest metric, so OSPF puts that route in the routing table. However, when the metrics tie for multiple routes to the same subnet, the router can put multiple equal-cost routes in the routing table (the default is four different routes) based on the setting of the **maximum-paths** *number* router subcommand. For example, if an internetwork has six possible paths between some parts of the network, and the engineer wants all routes to be used, the routers can be configured with the **maximum-paths 6** subcommand under **router ospf**.

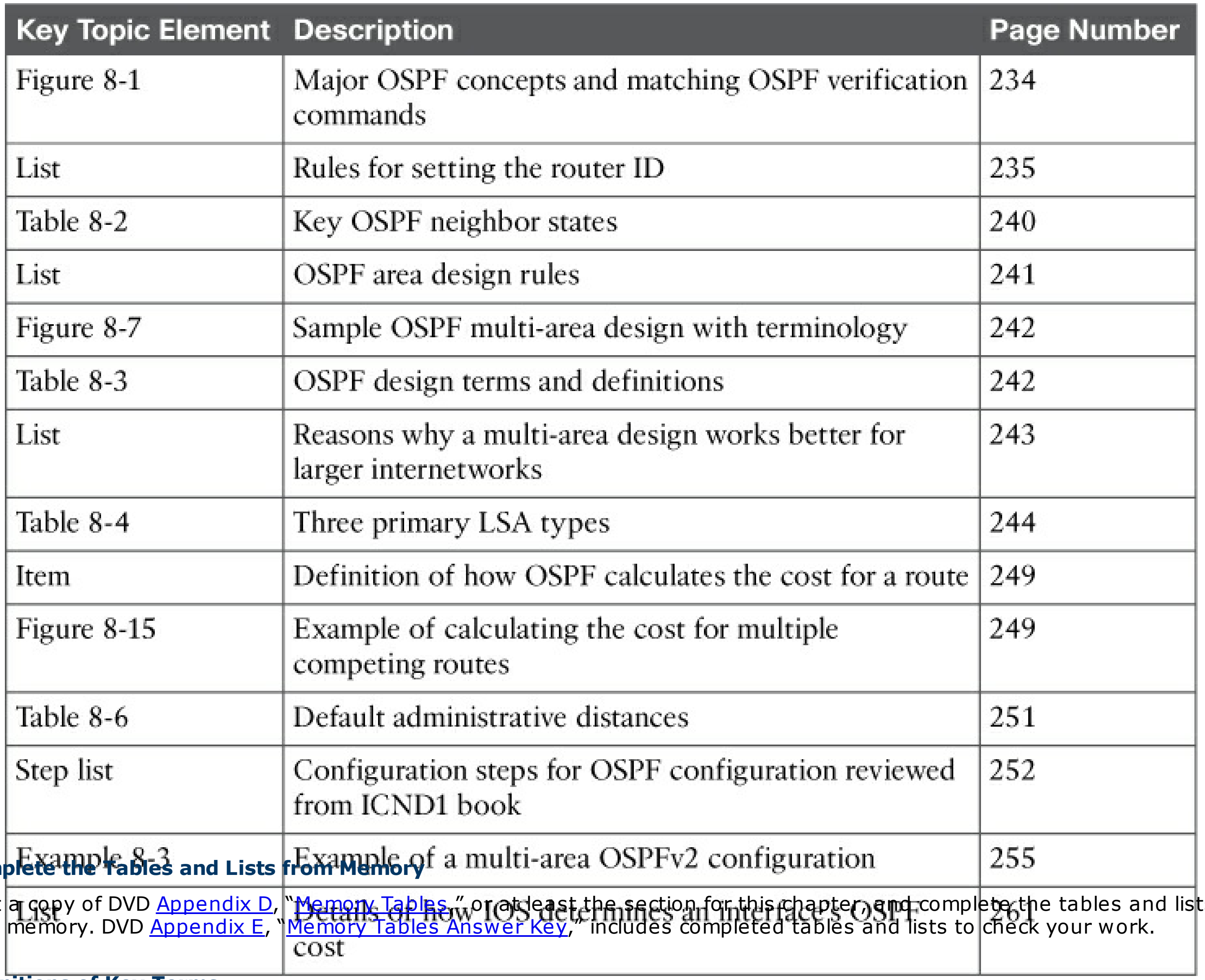
The more challenging concept relates to how the routers use those multiple routes. A router could load balance the packets on a per-packet basis. For example, if the router has three equal-cost OSPF routes for the same subnet in the routing table, the router could send the one packet over the first route, the next packet over the second route, the next packet over the third route, and then start over with the first route for the next packet. Alternatively, the load balancing could be on a per-destination IP address basis.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 8-9 lists these key topics and where each is discussed.

Table 8-9. Key Topics for Chapter 8



Key Topic Element	Description	Page Number
Figure 8-1	Major OSPF concepts and matching OSPF verification commands	234
List	Rules for setting the router ID	235
Table 8-2	Key OSPF neighbor states	240
List	OSPF area design rules	241
Figure 8-7	Sample OSPF multi-area design with terminology	242
Table 8-3	OSPF design terms and definitions	242
List	Reasons why a multi-area design works better for larger internetworks	243
Table 8-4	Three primary LSA types	244
Item	Definition of how OSPF calculates the cost for a route	249
Figure 8-15	Example of calculating the cost for multiple competing routes	249
Table 8-6	Default administrative distances	251
Step list	Configuration steps for OSPF configuration reviewed from ICND1 book	252
Example 8-3	Example of a multi-area OSPFv2 configuration	255
List	Details of how IOS determines an interface's OSPF cost	261

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix D, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix E, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Definitions of Key Terms

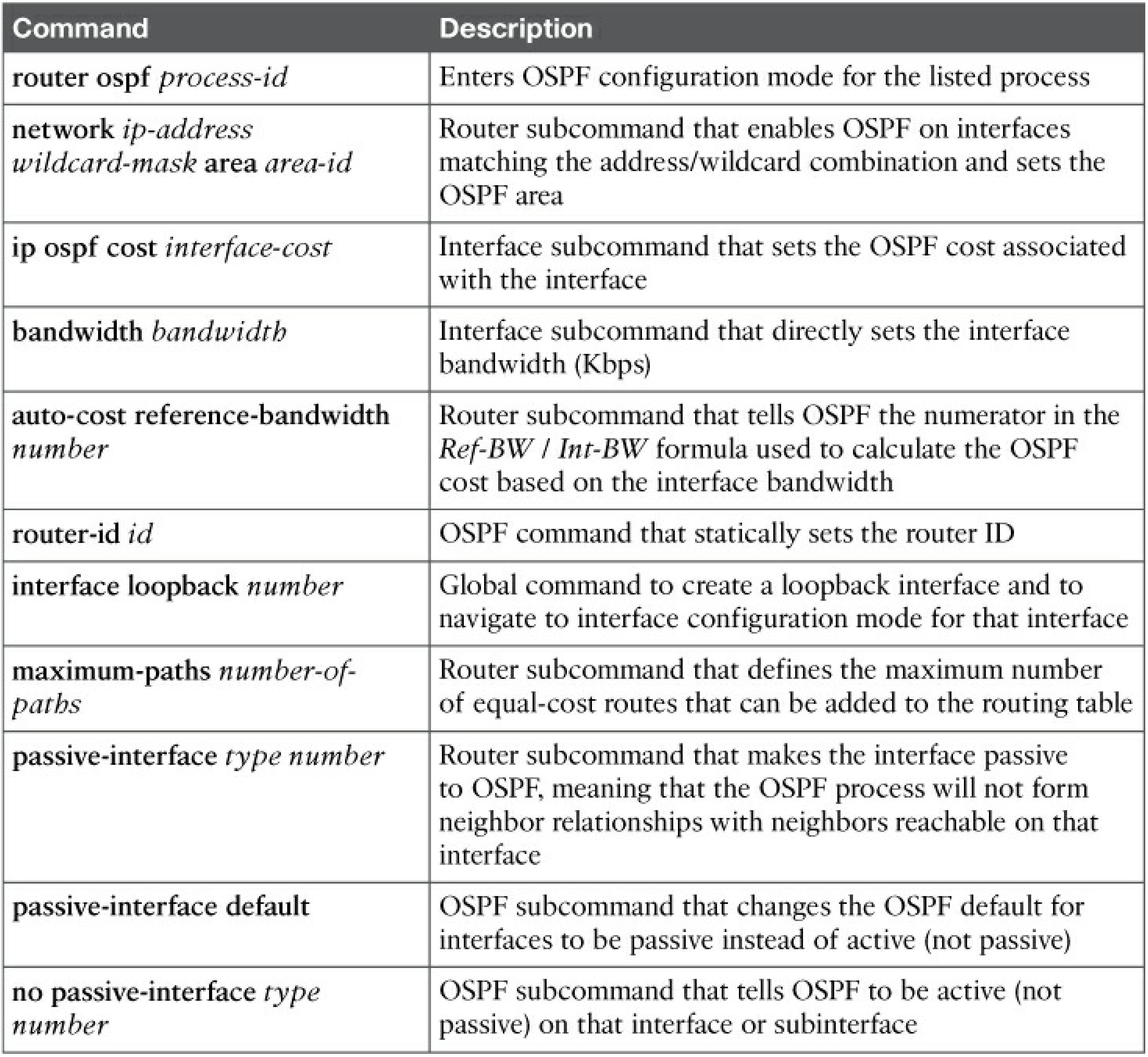
After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22 directs you in how to use these terms for late-stage preparation for the exam.

- 2-way state
- full state
- Area Border Router (ABR)
- designated router
- backup designated router
- fully adjacent
- Hello Interval
- Dead Interval
- link-state advertisement
- link-state update
- neighbor
- router ID (RID)
- topology database
- shortest path first (SPF)
- internal router
- router LSA
- network LSA
- summary LSA
- backbone area

Command Reference to Check Your Memory

Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table, read the descriptions on the right side, and see if you remember the command.

Table 8-10. Chapter 8 Configuration Command Reference



Command	Description
router ospf *process-id*	Enters OSPF configuration mode for the listed process
network *ip-address wildcard-mask* **area** *area-id*	Router subcommand that enables OSPF on interfaces matching the address/wildcard combination and sets the OSPF area
ip ospf cost *interface-cost*	Interface subcommand that sets the OSPF cost associated with the interface
bandwidth *bandwidth*	Interface subcommand that directly sets the interface bandwidth (Kbps)
auto-cost reference-bandwidth *number*	Router subcommand that tells OSPF the numerator in the *Ref-BW / Int-BW* formula used to calculate the OSPF cost based on the interface bandwidth
router-id *id*	OSPF command that statically sets the router ID
interface loopback *number*	Global command to create a loopback interface and to navigate to interface configuration mode for that interface
maximum-paths *number-of-paths*	Router subcommand that defines the maximum number of equal-cost routes that can be added to the routing table
passive-interface *type number*	Router subcommand that makes the interface passive to OSPF, meaning that the OSPF process will not form neighbor relationships with neighbors reachable on that interface
passive-interface default	OSPF subcommand that changes the OSPF default for interfaces to be passive instead of active (not passive)
no passive-interface *type number*	OSPF subcommand that tells OSPF to be active (not passive) on that interface or subinterface

Table 8-11. Chapter 8 EXEC Command Reference

Command	Description
show ip ospf	Lists information about the OSPF process running on the router, including the OSPF router ID, areas to which the router connects, and the number of interfaces in each area.
show ip ospf interface brief	Lists the interfaces on which the OSPF protocol is enabled (based on the **network** commands), including passive interfaces.
show ip ospf interface *type number*	Lists a long section of settings, status, and counters for OSPF operation on all interfaces, or on the listed interface, including the Hello and Dead Timers.
show ip protocols	Shows routing protocol parameters and current timer values.
show ip ospf neighbor [*type number*]	Lists brief output about neighbors, identified by neighbor router ID, including current state, with one line per neighbor; optionally, limit the output to neighbors on the listed interface.
show ip ospf neighbor *neighbor-ID*	Lists the same output as the **show ip ospf neighbor detail** command, but only for the listed neighbor (by neighbor RID).
show ip ospf database	Lists a summary of the LSAs in the database, with one line of output per LSA. It is organized by LSA type (first type 1, then type 2, and so on).
show ip route	Lists all IPv4 routes.
show ip route ospf	Lists routes in the routing table learned by OSPF.
show ip route *ip-address mask*	Shows a detailed description of the route for the listed subnet/mask.
clear ip ospf process	Resets the OSPF process, resetting all neighbor relationships and also causing the process to make a choice of OSPF RID.

Chapter 9. Understanding EIGRP Concepts

This chapter covers the following exam topics:

IP Routing Technologies

- Configure and verify EIGRP (single AS)
  - Feasible Distance *Feasible Successors* Administrative distance
  - Feasibility condition
  - Metric composition
  - Router ID
  - Auto summary
  - Path selection
  - Load balancing
    - Equal
    - Unequal
  - Passive interface
- Differentiate methods of routing and routing protocols
  - split horizon
  - metric
  - next hop

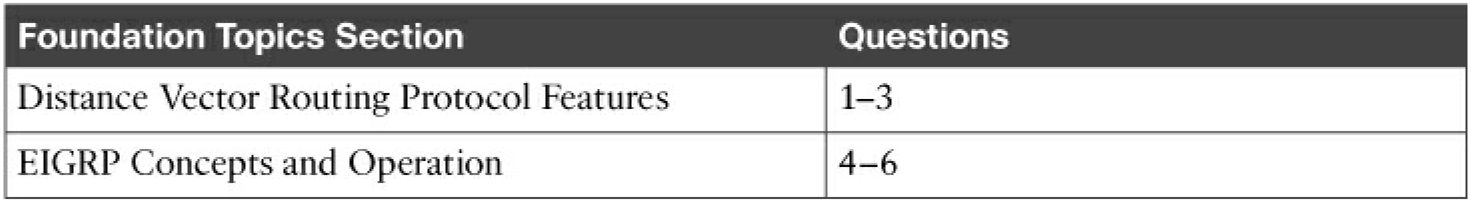
This chapter takes an in-depth look at a second option for an IPv4 routing protocol: the Enhanced Interior Gateway Routing Protocol, or EIGRP. This Cisco-proprietary routing protocol uses configuration commands much like Open Shortest Path First (OSPF), with the primary difference being that EIGRP configuration does not need to refer to an area. However, EIGRP does not use link-state (LS) logic, instead using some advanced distance vector (DV) logic. So, this chapter discusses quite a bit of detail about how routing protocols work and how EIGRP works before moving on to EIGRP configuration.

This chapter breaks the topics into two major sections. The first looks at the details of how DV routing protocols work, comparing the basic features of RIP with the more advanced features of EIGRP. The second major section looks at the specifics of EIGRP, including EIGRP neighbors, exchanging routing information, and calculating the currently best routes to reach each possible subnet.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the Exam Preparation Tasks section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 9-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Distance Vector Routing Protocol Features	1–3
EIGRP Concepts and Operation	4–6

1. Which of the following distance vector features prevents routing loops by causing the routing protocol to advertise only a subset of known routes, as opposed to the full routing table, under normal stable conditions?

- **a.** Route poisoning
- **b.** Poison reverse
- **c.** DUAL
- **d.** Split horizon

2. Which of the following distance vector features prevents routing loops by advertising an infinite metric route when a route fails?

- **a.** Dijkstra SPF
- **b.** DUAL
- **c.** Split horizon
- **d.** Route poisoning

3. Routers A and B use EIGRP. How does router A watch for the status of router B so that router A can react if router B fails?

- **a.** By using EIGRP Hello messages, with A needing to receive periodic Hello messages to believe B is still working
- **b.** By using EIGRP update messages, with A needing to receive periodic update messages to believe B is still working

- **c.** Using a periodic ping of B’s IP address based on the EIGRP neighbor timer
- **d.** None of the above

4. Which of the following affect the calculation of EIGRP metrics when all possible default values are used? (Choose two answers.)

- **a.** Bandwidth
- **b.** Delay
- **c.** Load
- **d.** Reliability
- **e.** MTU
- **f.** Hop count

5. Which of the following is true about the concept of EIGRP feasible distance?

- **a.** A route’s feasible distance is the calculated metric of a feasible successor route.
- **b.** A route’s feasible distance is the calculated metric of the successor route.
- **c.** The feasible distance is the metric of a route from a neighboring router’s perspective.
- **d.** The feasible distance is the EIGRP metric associated with each possible route to reach a subnet.

6. Which of the following is true about the concept of EIGRP reported distance?

- **a.** A route’s reported distance is the calculated metric of a feasible successor route.
- **b.** A route’s reported distance is the calculated metric of the successor route.
- **c.** A route’s reported distance is the metric of a route from a neighboring router’s perspective.
- **d.** The reported distance is the EIGRP metric associated with each possible route to reach a subnet.

Answers to the “Do I Know This Already?” quiz:

1 D **2** D **3** A **4** A and B **5** B **6** C

Foundation Topics

EIGRP and Distance Vector Routing Protocols

IPv4’s long history has resulted in many competing interior gateway protocols (IGP). Each of those different IPv4 IGPs differs in some ways, including the underlying routing protocol algorithms like link state and distance vector. This first section of the chapter looks at how EIGRP acts like distance vector routing protocols to some degree, while at the same time, EIGRP does not fit easily into any category at all.

In particular, this first section first positions EIGRP against the other common IPv4 routing protocols. Then this section looks at basic DV concepts as implemented with RIP. Using the simpler RIP to learn the basics helps the discussion focus on the DV concepts. This section ends then with a discussion of how EIGRP uses DV features but in a more efficient way than RIP uses them.

Introduction to EIGRP

Historically speaking, the first IPv4 routing protocols used DV logic. RIP Version 1 (RIP-1) was the first popularly used IP routing protocol, with the Cisco-proprietary Interior Gateway Routing Protocol (IGRP) being introduced a little later, as shown in Figure 9-1.

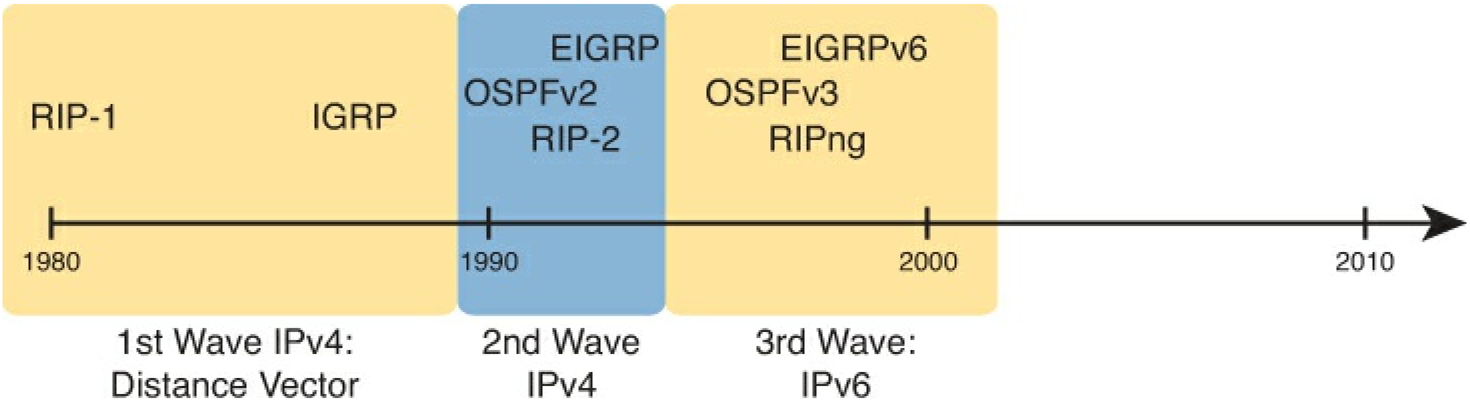

EIGRP
EIGRPv6
RIP-1
IGRP
OSPFv2
RIP-2
OSPFv3
RIPng
1980
1990
2000
2010
1st Wave IPv4: Distance Vector
2nd Wave IPv4
3rd Wave: IPv6

Figure 9-1. Timeline for IP IGPs

By the early 1990s, business and technical factors pushed the IPv4 world toward a second wave of better routing protocols. First, RIP-1 and IGRP had some technical limitations, even though they were great options for the technology levels of the 1980s. The bigger motivation for better routing protocols was the huge movement toward TCP/IP in the 1990s. Many enterprises migrated from older vendor-proprietary networks to networks built with routers, LANs, and TCP/IP. These businesses needed better performance from their routing protocols, including better metrics and better convergence. All these factors led to the introduction of a new wave of IPv4 Interior routing protocols: RIP Version 2 (RIP-2), OSPF Version 2 (OSPFv2), and EIGRP.

> **Note**
>
> As an aside, many documents refer to EIGRP's support for learning IPv4 routes simply as EIGRP, and EIGRP support for IPv6 as EIGRPv6. This book follows that same convention. OSPF RFCs define specific versions, OSPF Version 2 (OSPFv2) learning IPv4 routes, and OSPF Version 3 (OSPFv3) learning IPv6 routes.

Even today, EIGRP and OSPFv2 remain the two primary competitors as the IPv4 routing protocol to use in a modern enterprise IPv4 internetwork. RIP-2 has fallen away as a serious competitor, in part due to its less robust hop-count metric, and in part due to its slower (worse) convergence time. Even today, you can walk in to most corporate networks and find either EIGRP or OSPFv2 as the routing protocol used throughout the network.

So, with so many IPv4 routing protocols, how does a network engineer choose which routing protocol to use? Well, consider two key points about EIGRP that drive engineers toward wanting to use it:

Key Topic

- EIGRP uses a robust metric based on both link bandwidth and link delay, so routers make good choices about the best route to use (see Figure 9-2).

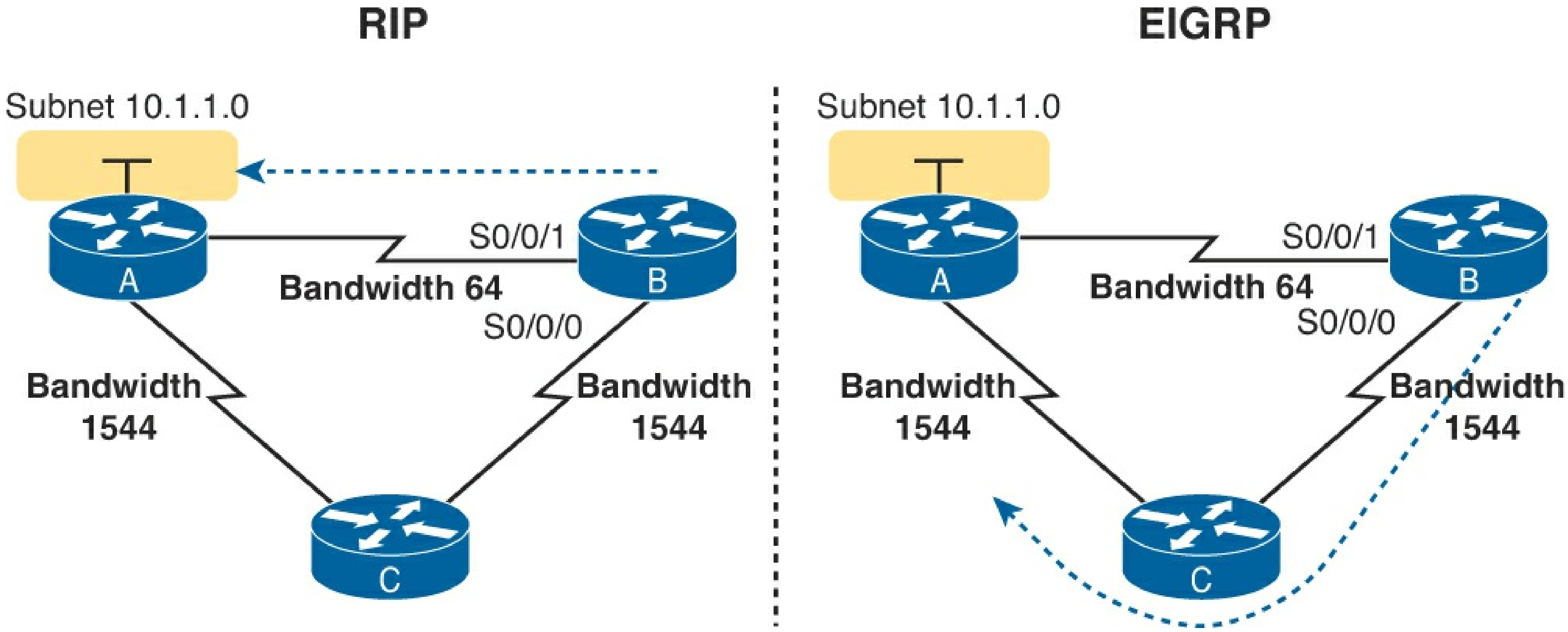

RIP
EIGRP
Subnet 10.1.1.0
A
B
C
S0/0/1
S0/0/0
Bandwidth 64
Bandwidth 1544
Bandwidth 1544
Subnet 10.1.1.0
A
B
C
S0/0/1
S0/0/0
Bandwidth 64
Bandwidth 1544
Bandwidth 1544

Figure 9-2. EIGRP Choosing the Longer But Better Route to Subnet 10.1.1.0

- EIGRP converges quickly, meaning that when something changes in the internetwork, EIGRP quickly finds the currently best loop-free routes to use.

For example, RIP uses a basic metric of hop count, meaning the number of routers between the destination subnet and the local router. These metrics make RIP to choose a short route (fewest router hops away), even shorter routes with slow links, so that route might not be the truly best route. EIGRP's metric calculation uses a math formula that avoids routes with slow links by giving those routes worse (higher) metrics. Figure 9-2 shows an example.

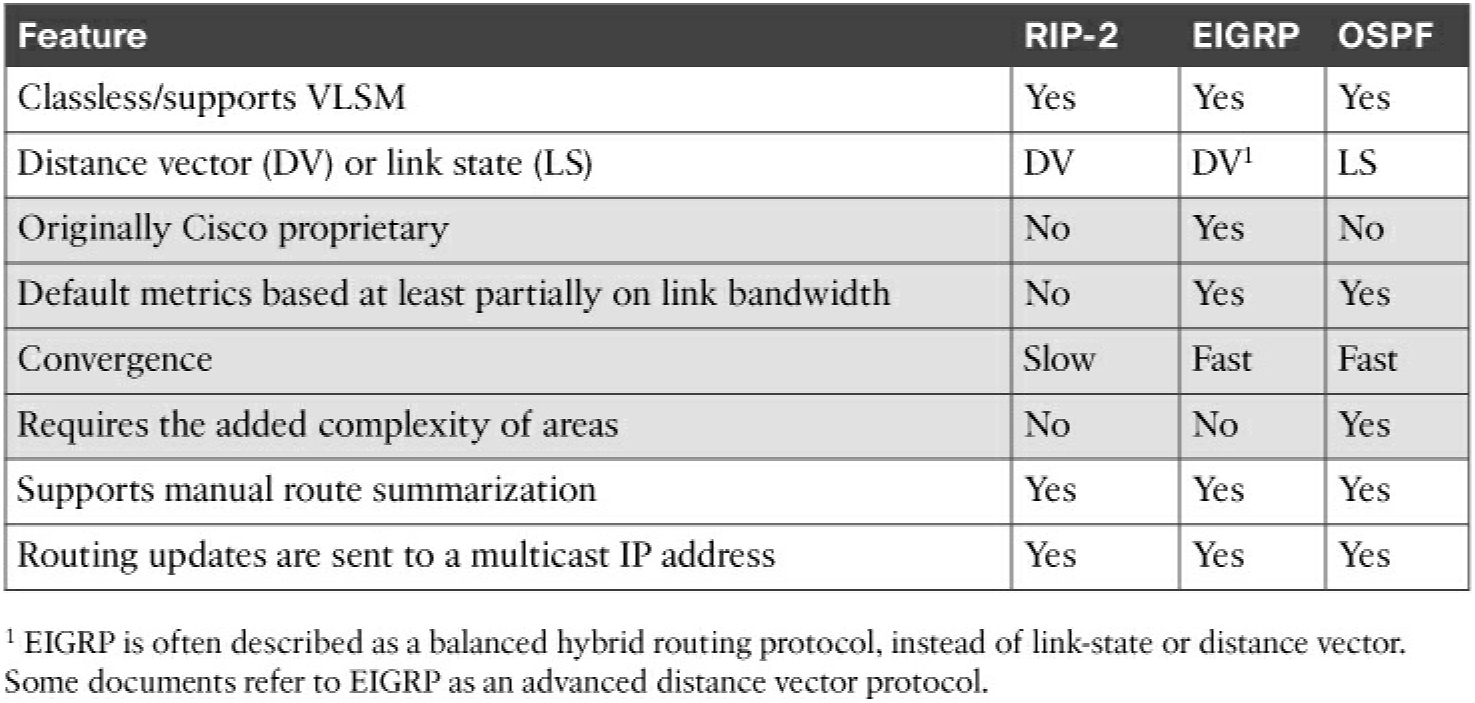
Traditionally, from the introduction of EIGRP in the 1990s until 2013, the one big negative about EIGRP was that Cisco kept the protocol as a Cisco-proprietary protocol. That is, to run Cisco's EIGRP, you had to buy Cisco routers. In an interesting change, Cisco published EIGRP as an informational RFC, meaning that now other vendors can choose to implement EIGRP as well. In the past, many companies chose to use OSPF rather than EIGRP to give themselves options for what router vendor to use for future router hardware purchases. In the future, it might be that you can buy some routers from Cisco, some from other vendors, and still run EIGRP on all routers.

Today, EIGRP and OSPFv2 remain the two best options for IPv4 interior routing protocols. Both converge quickly. Both use a good metric that considers link speeds when choosing the route. EIGRP can be much simpler to implement. Many reasonable network engineers have made these comparisons over the years, with some choosing OSPFv2, and others choosing EIGRP.

For reference and study, Table 9-2 lists several features of OSPFv2 and EIGRP, as well as RIP-2. (Note that the table mentions a topic not yet discussed in this book—autosummarization—as discussed in Chapter 10's section "Autosummarization and Discontiguous Networks.")

Key Topic

Table 9-2. Interior IP Routing Protocols Compared



Feature	RIP-2	EIGRP	OSPF
Classless/supports VLSM	Yes	Yes	Yes
Distance vector (DV) or link state (LS)	DV	DV[1]	LS
Originally Cisco proprietary	No	Yes	No
Default metrics based at least partially on link bandwidth	No	Yes	Yes
Convergence	Slow	Fast	Fast
Requires the added complexity of areas	No	No	Yes
Supports manual route summarization	Yes	Yes	Yes
Routing updates are sent to a multicast IP address	Yes	Yes	Yes

[1] EIGRP is often described as a balanced hybrid routing protocol, instead of link-state or distance vector. Some documents refer to EIGRP as an advanced distance vector protocol.

Basic Distance Vector Routing Protocol Features

EIGRP does not fit cleanly into the category of DV routing protocols or LS routing protocols. However, it most closely matches DV protocols. The next topic explains the basics of DV routing protocols as originally implemented with RIP, to give a frame of reference of how DV protocols work. In particular, the next examples show routes that use RIP's simple hop-count metric, which, although a poor option in real networks today, is a much simpler option for learning than EIGRP's more complex metric.

The Concept of a Distance and a Vector

The term *distance vector* describes what a router knows about each route. At the end of the process, when a router learns about a route to a subnet, all the router knows is some measurement of distance (the metric) and the next-hop router and outgoing interface to use for that route (a vector, or direction).

Figure 9-3 shows a view of both the vector and the distance as learned with RIP. The figure shows the flow of RIP messages that cause R1 to learn some IPv4 routes, specifically three routes to reach subnet X:

- The four-hop route through R2
- The three-hop route through R5
- The two-hop route through R7

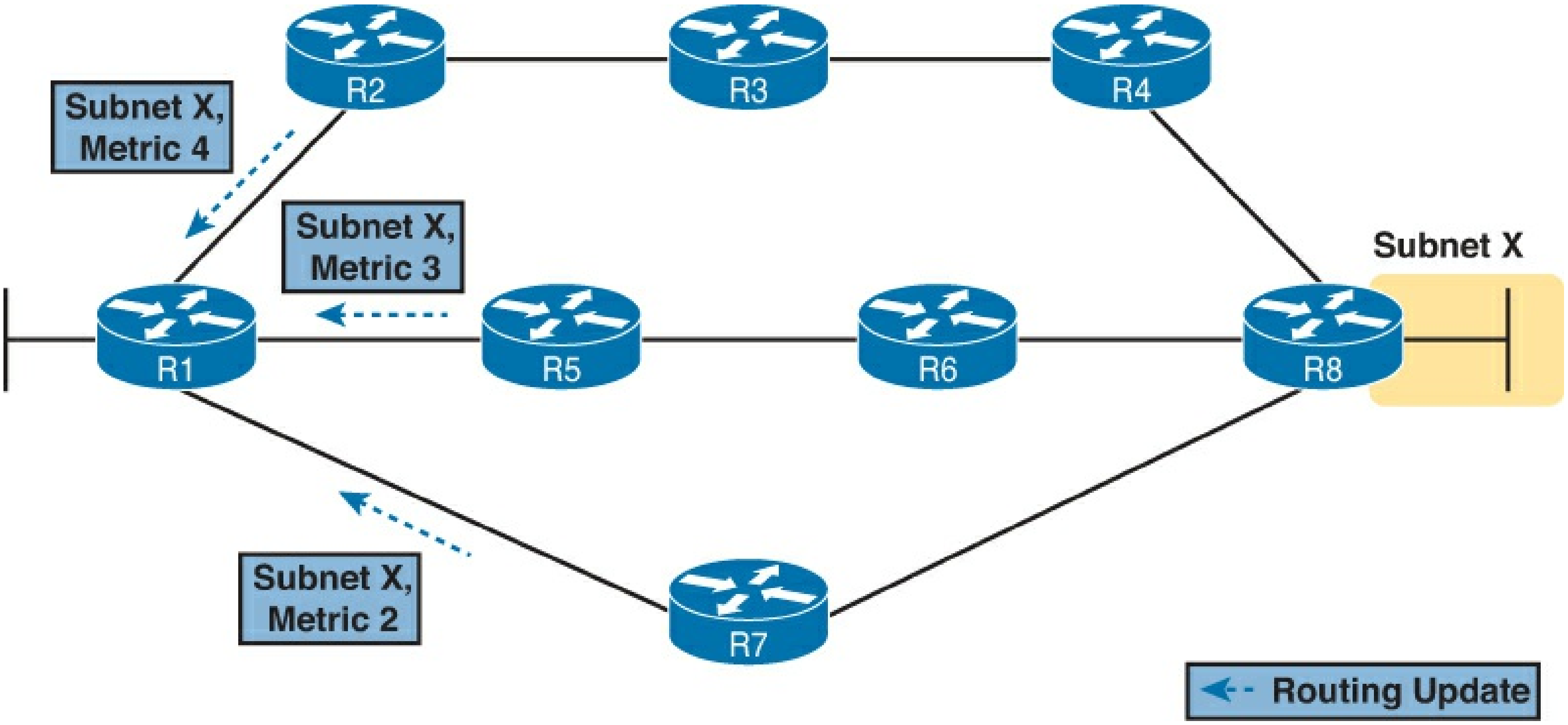

R2
R3
R4
Subnet X, Metric 4
Subnet X, Metric 3
Subnet X
R1
R5
R6
R8
Subnet X, Metric 2
R7
Routing Update

Figure 9-3. Information Learned Using DV Protocols

DV protocols learn two pieces of information about a possible route to reach a subnet: the distance (metric), and the vector (the next hop router). In this case, R1 learns three routes to reach subnet X. When only one route for a single subnet exists, the router chooses that one route. However, with the three possible routes in this case, R1 picks the two-hop route through next-hop router R7, because that route has the lowest RIP metric.

While Figure 9-3 shows how R1 learns the routes with RIP Updates, Figure 9-4 gives a better view into R1's distance vector logic. R1 knows three routes, each with:

Key Topic

Distance: The metric for a possible route

Vector: The direction, based on the next-hop router for a possible route

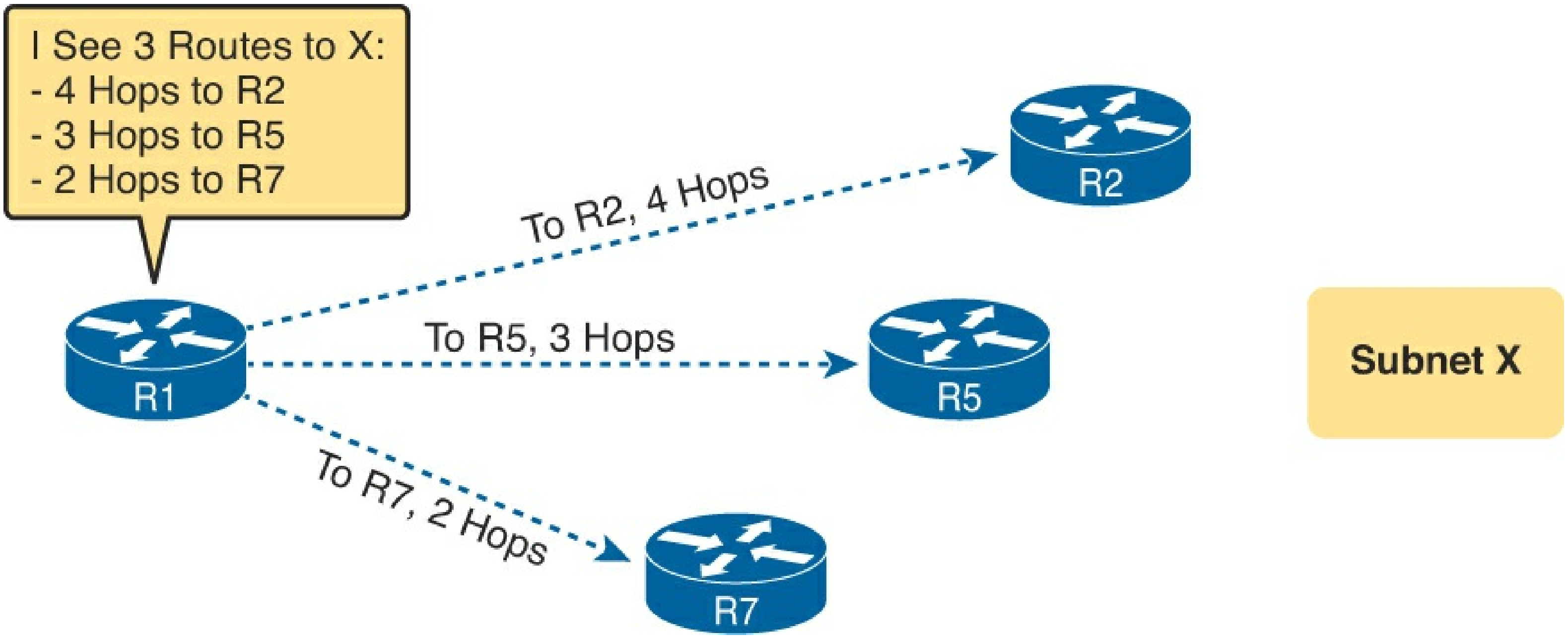

I See 3 Routes to X:
- 4 Hops to R2
- 3 Hops to R5
- 2 Hops to R7
R2
To R2, 4 Hops
To R5, 3 Hops
R5
Subnet X
R1
To R7, 2 Hops
R7

Figure 9-4. Graphical Representation of the DV Concept

Note that R1 knows no other topology information about the internetwork. Unlike LS protocols, RIP's DV logic has no idea about the overall topology, instead just knowing about next-hop routers and metrics.

Full Update Messages and Split Horizon

DV routing protocols have a couple of functions that require messages between neighboring routers.

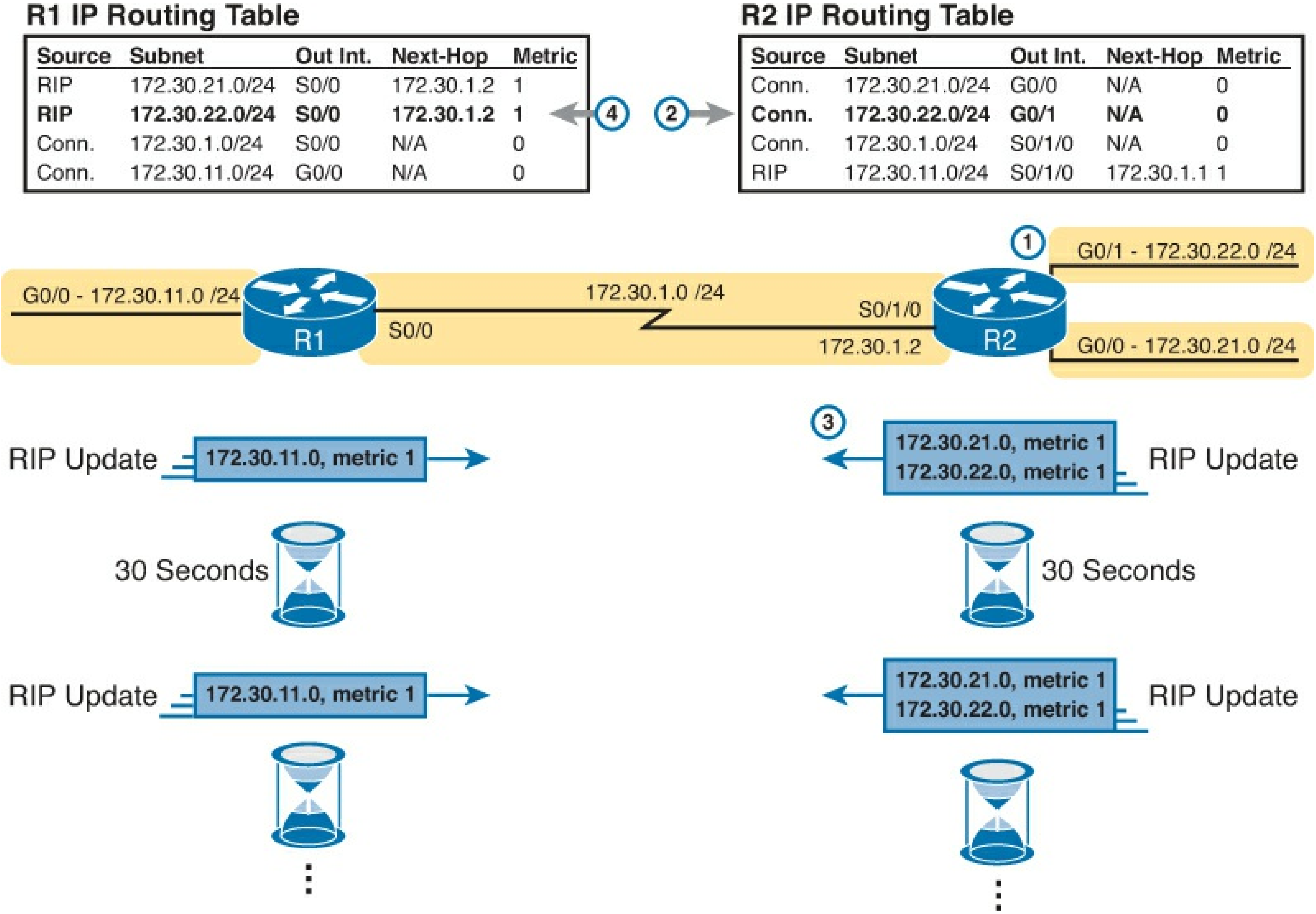
First, routers need to send routing information inside some message, so that the sending router can advertise routing information to neighboring routers. For instance, in Figure 9-3, R1 received RIP messages to learn routes. As discussed in Chapter 8, OSPF calls those messages link-state updates (LSU). RIP and EIGRP both happen to call their messages an update message.

In addition, routers need to monitor whether each neighboring router is still working or not; routers do so by sending and receiving regular messages with each neighbor. By quickly realizing when a neighboring router fails, routers can more quickly converge to use any still-available routes.

All routing protocols use some mechanism to monitor the state of neighboring routers. OSPF uses Hello messages, on a relatively short timer (default 10 seconds on many interfaces). EIGRP happens to use a Hello message and process, as well. However, old basic DV protocols like RIP do not use a separate Hello type of message, instead using the same update message both to advertise routing information and be aware of whether the neighboring router is still alive. In other words, the function of advertising routing information, and the function of monitoring neighbor state, is done with the same update message.

These older basic DV routing protocols like RIP send periodic full routing updates based on a relatively short timer. *Full update* means that a router advertises all its routes, using one or more RIP update messages, no matter whether the route has changed or not. *Periodic* means that the router sends the message based on a timed period (30 seconds with RIP).

Figure 9-5 illustrates this concept in an internetwork with two routers, three LAN subnets, and one WAN subnet. The figure shows both routers' full routing tables, plus listing the periodic full updates sent by each router.



R1 IP Routing Table

Source	Subnet	Out Int.	Next-Hop	Metric
RIP	172.30.21.0/24	S0/0	172.30.1.2	1
RIP	**172.30.22.0/24**	**S0/0**	**172.30.1.2**	**1**
Conn.	172.30.1.0/24	S0/0	N/A	0
Conn.	172.30.11.0/24	G0/0	N/A	0

R2 IP Routing Table

Source	Subnet	Out Int.	Next-Hop	Metric
Conn.	172.30.21.0/24	G0/0	N/A	0
Conn.	**172.30.22.0/24**	**G0/1**	**N/A**	**0**
Conn.	172.30.1.0/24	S0/1/0	N/A	0
RIP	172.30.11.0/24	S0/1/0	172.30.1.1	1

Figure 9-5. Normal Steady-State RIP Operations: Full Update with Split Horizon

This figure shows a lot of information, so take the time to work through the details. For example, consider what router R1 learns for subnet 172.30.22.0/24, which is the subnet connected to R2's G0/1 interface:

1. R2 interface G0/1 has an IP address, and is in an up/up state.
2. R2 adds a connected route for 172.30.22.0/24, off interface G0/1, to R2's routing table.
3. R2 advertises its route for 172.30.22.0/24 to R1, with metric 1, meaning that R1's metric to reach this subnet will be metric 1 (hop count 1).
4. R1 adds a route for subnet 172.30.22.0/24, listing it as a RIP learned route with metric 1.

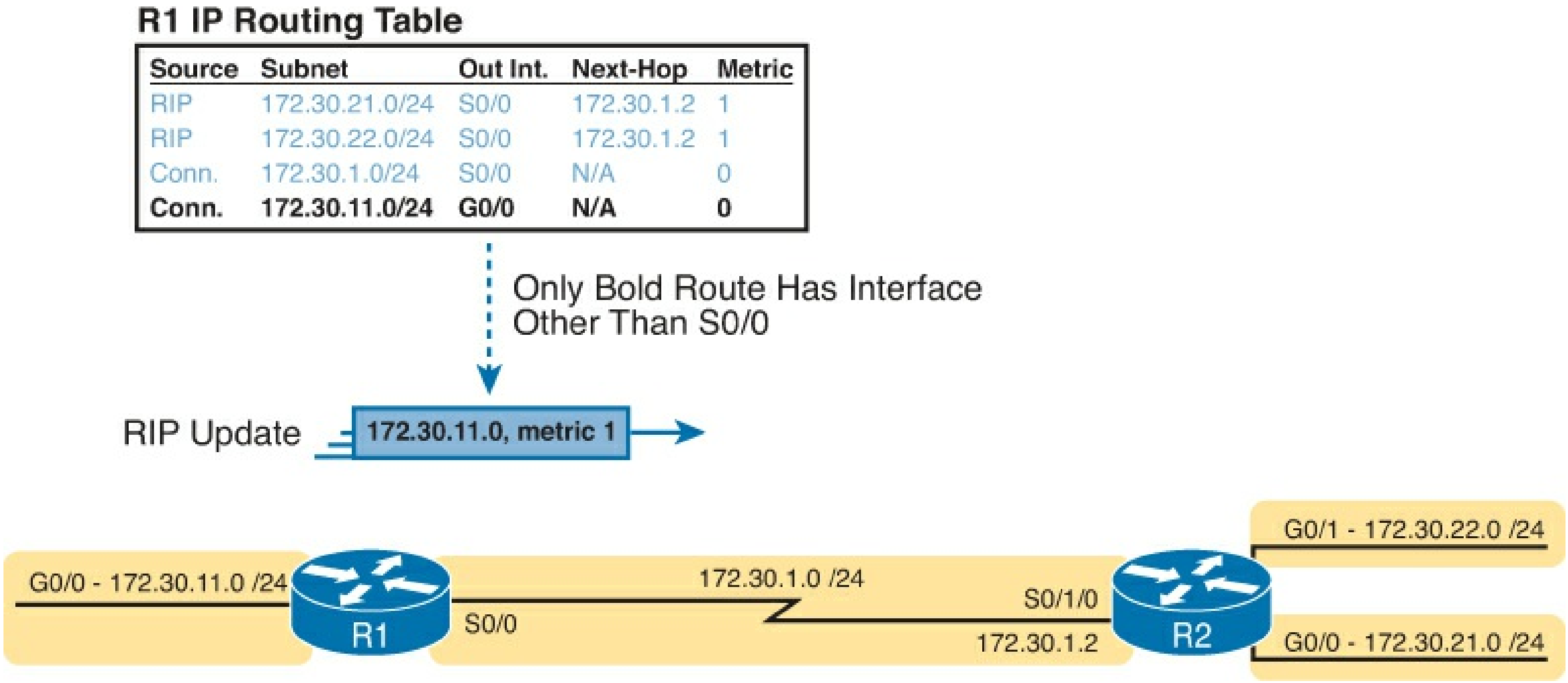
Also, take a moment to focus more on the route learned at Step 4: The bold route in R1's routing table. This route is for 172.30.22.0/24, as learned from R2. It lists R1's local S0/0 interface as the outgoing interface, because R1 receive the update on that interface. It also lists R2's serial IP address of 172.30.1.2 as next-hop router because that's the IP address from which R1 learned the route.

Next, look at the bottom of the figure, which shows the RIP update message being used to monitor neighbor state. The routers repeat the exact same update message based on 30-second timers. Note that in this internetwork, if nothing changed for a year, with RIP, every 30 seconds, the routers would repeat this same routing information to each other. Why? If a router fails to receive the update messages for a defined time period, the local router knows the silent neighbor has failed.

Finally, the figure shows an example of *split horizon*. Note that both routers list all four subnets in their IP routing tables, yet the RIP update messages do not list four subnets. The reason? Split horizon. Split horizon is a DV feature that tells the routing protocol to not advertise some routes in an update sent out an interface: routes that list that interface as the outgoing interface. Those routes that are not advertised on an interface usually include the routes learned in routing updates received on that interface.

Split horizon is difficult to learn by reading words, and much easier to learn by seeing an example. Figure 9-6 continues the same example as 9-5, but focusing on R1's RIP update sent out R1's S0/0 interface to R2. This figure shows R1's routing table with three light-colored routes, all of which list S0/0 as the outgoing interface. When building the RIP update to send out S0/0, split-horizon rules tell R1 to ignore those light-colored routes. Only the bold route, which does not list S0/0 as an outgoing interface, can be included in the RIP update sent out S0/0.

Key Topic



R1 IP Routing Table

Source	Subnet	Out Int.	Next-Hop	Metric
RIP	172.30.21.0/24	S0/0	172.30.1.2	1
RIP	172.30.22.0/24	S0/0	172.30.1.2	1
Conn.	172.30.1.0/24	S0/0	N/A	0
Conn.	**172.30.11.0/24**	**G0/0**	**N/A**	**0**

Figure 9-6. R1 Does Not Advertise Three Routes due to Split Horizon

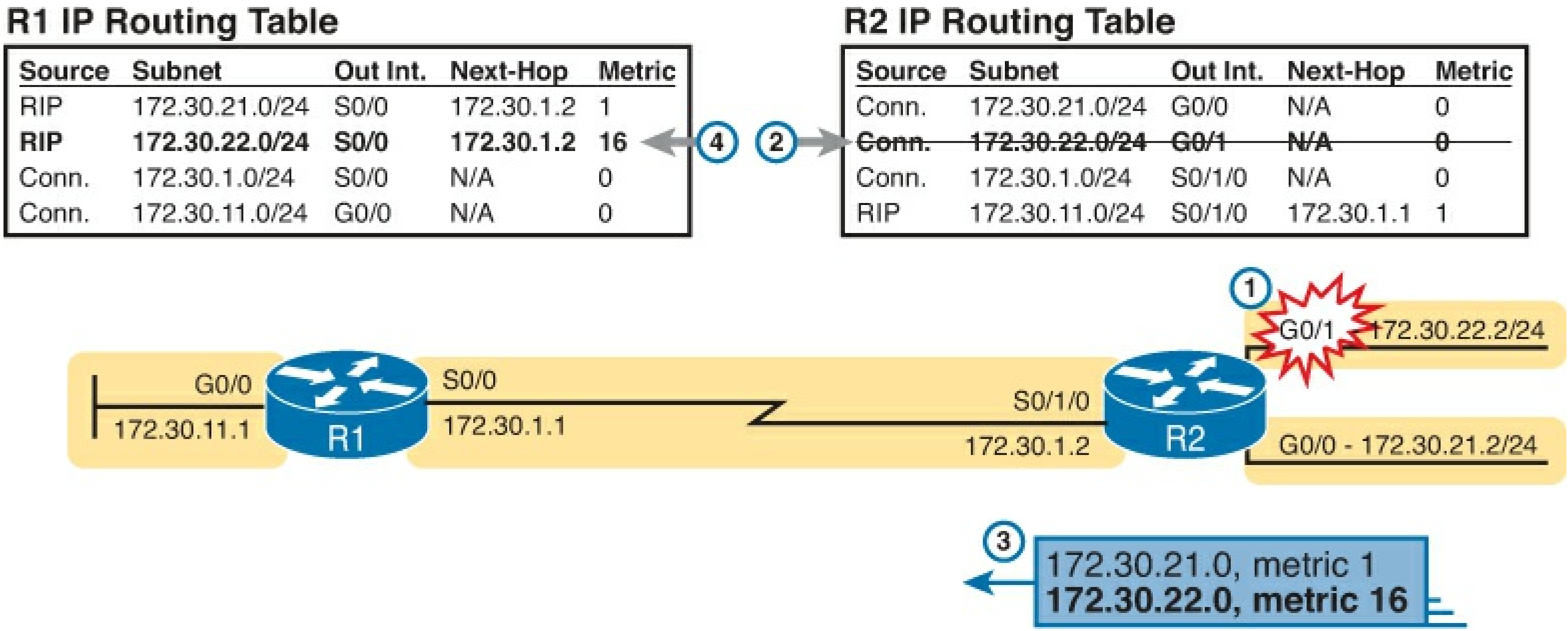
Route Poisoning

DV protocols help prevent routing loops by ensuring that every router learns that the route has failed, through every means possible, as quickly as possible. One of these features, *route poisoning*, helps all routers know for sure that a route has failed.

Route poisoning refers to the practice of advertising a failed route, but with a special metric value called *infinity*. Routers consider routes advertised with an infinite metric to have failed.

Route poisoning works a little like in real life, when two people have a conflict. They can ignore the conflict, and just not talk about it. However, it helps if the two people openly talk about the problem, even if the process is a bit uncomfortable, so both people can make a reasonable choice about what to do next. Route poisoning lets two routers talk openly about a particular type of problem: a failed route.

Figure 9-7 shows an example of route poisoning with RIP, with R2's G0/1 interface failing, meaning that R2's route for 172.30.22.0/24 has failed. RIP defines infinity as 16.



R1 IP Routing Table

Source	Subnet	Out Int.	Next-Hop	Metric
RIP	172.30.21.0/24	S0/0	172.30.1.2	1
RIP	**172.30.22.0/24**	**S0/0**	**172.30.1.2**	**16**
Conn.	172.30.1.0/24	S0/0	N/A	0
Conn.	172.30.11.0/24	G0/0	N/A	0

R2 IP Routing Table

Source	Subnet	Out Int.	Next-Hop	Metric
Conn.	172.30.21.0/24	G0/0	N/A	0
~~Conn.~~	~~172.30.22.0/24~~	~~G0/1~~	~~N/A~~	~~0~~
Conn.	172.30.1.0/24	S0/1/0	N/A	0
RIP	172.30.11.0/24	S0/1/0	172.30.1.1	1

172.30.21.0, metric 1
172.30.22.0, metric 16

Figure 9-7. Route Poisoning

Figure 9-7 shows the following process:

1. R2's G0/1 interface fails.
2. R2 removes its connected route for 172.30.22.0/24 from its routing table.
3. R2 advertises 172.30.22.0 with an infinite metric (which for RIP is 16).
4. Depending on other conditions, R1 either immediately removes the route to 172.30.22.0 from its routing table, or marks the route as unusable (with an infinite metric) for a few minutes before removing the route.

By the end of this process, router R1 knows for sure that its old route for subnet 172.30.22.0/24 has failed, which helps R1 not introduce any looping IP routes.

Each routing protocol has its own definition of an infinite metric. RIP uses 16, as shown in the figure, with 15 being a valid metric for a usable route. EIGRP has long used $2^{32} - 1$ as infinity (a little over 4 billion), with some new IOS versions bumping that value to $2^{56} - 1$ (over 10^{16}). OSPFv2 uses $2^{24} - 1$ as infinity.

EIGRP as an Advanced DV Protocol

EIGRP acts a little like a DV protocol, and a little like no other routing protocol. Frankly, over the years, different Cisco documents and different books (mine included) have characterized EIGRP as either its own category, called a balanced hybrid routing protocol, or as some kind of advanced DV protocol.

Regardless of what label you put on EIGRP, the protocol uses several features that work either like basic DV protocols like RIP, or they work similarly enough. The next few pages walk through a few of the similarities and differences between RIP and EIGRP.

EIGRP Sends Partial Update Messages, As Needed

EIGRP does not use a short periodic update timer, sending a full update with all routes, like RIP does. EIGRP instead sends information about each route once, when the router learns the information. Then, the router sends only partial updates.

EIGRP partial updates are EIGRP update messages that list any new or changed information about a route. For instance, when a router interface fails, some routes will be affected. The router sends an immediate partial update message to any other neighboring EIGRP routers, listing new information. Or, when new routes become available, the router sends a partial update, about only the new routes. These update messages are not full updates, because they only contain changed or new information.

The idea works a little like OSPF's convention of flooding an LSA once inside an area. However, the router that creates an OSPF LSA does reflood that LSA every 30 minutes. EIGRP does not even bother to reflood its routing information. For instance, if the routing information about a route does not change for a year, EIGRP will literally remain silent about that route in its update messages for that whole year after it first advertises the route.

EIGRP Maintains Neighbor Status Using Hello

EIGRP does not send full or partial update messages based on a periodic timer, so EIGRP cannot rely on update messages to monitor the state of EIGRP neighbors. So, using the same basic ideas as OSPF, EIGRP defines a Hello message. The EIGRP Hello message and protocol defines that each router should send a periodic Hello message on each interface, so that all EIGRP routers know that the router is still working. Figure 9-8 shows the idea.

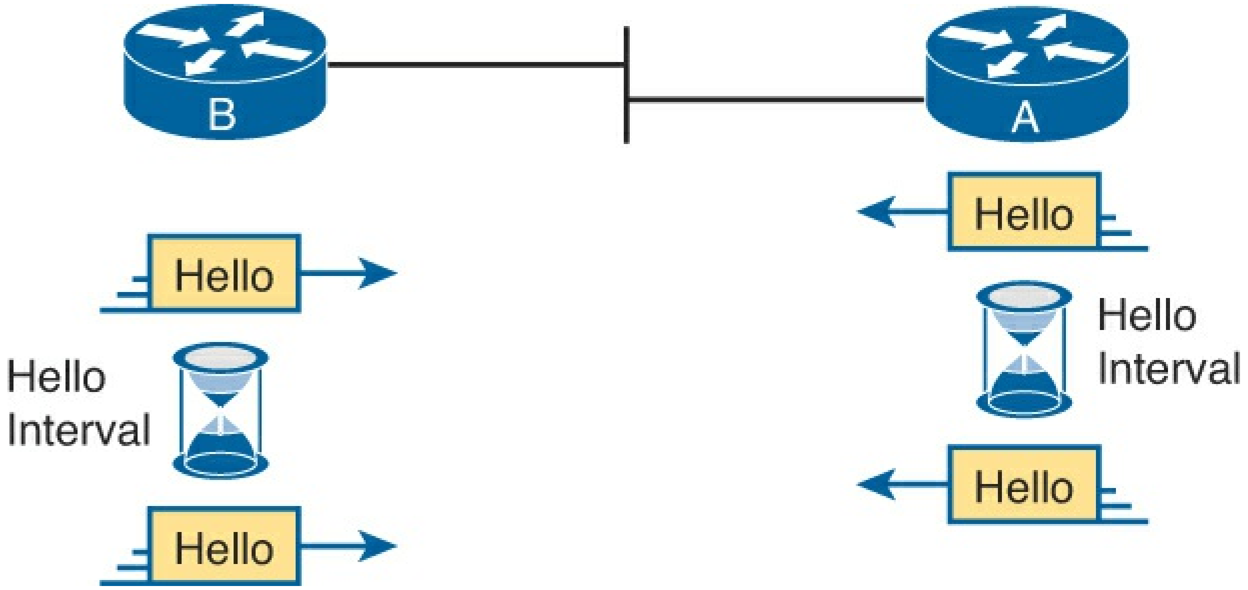


Figure 9-8. EIGRP Hello Packets

The routers use their own independent Hello Interval, which defines the time period between each EIGRP Hello. For instance, routers R1 and R2 do not have to send their Hellos at the same time. Routers also must receive a Hello from a neighbor with a time called the Hold Interval, with a default setting of four times the Hello Interval.

For instance, imagine both R1 and R2 use default settings of 5 and 15 for their Hello and Hold Intervals. Under normal conditions, R1 receives Hellos from R2 every 5 seconds, well within R1's Hold Interval (15 seconds) before R1 would consider R2 to have failed. If R2 does fail, R2 no longer sends Hello messages. R1 notices that 15 seconds pass without receiving a Hello from R2, so then R1 can choose new routes that do not use R1 as a next-hop router.

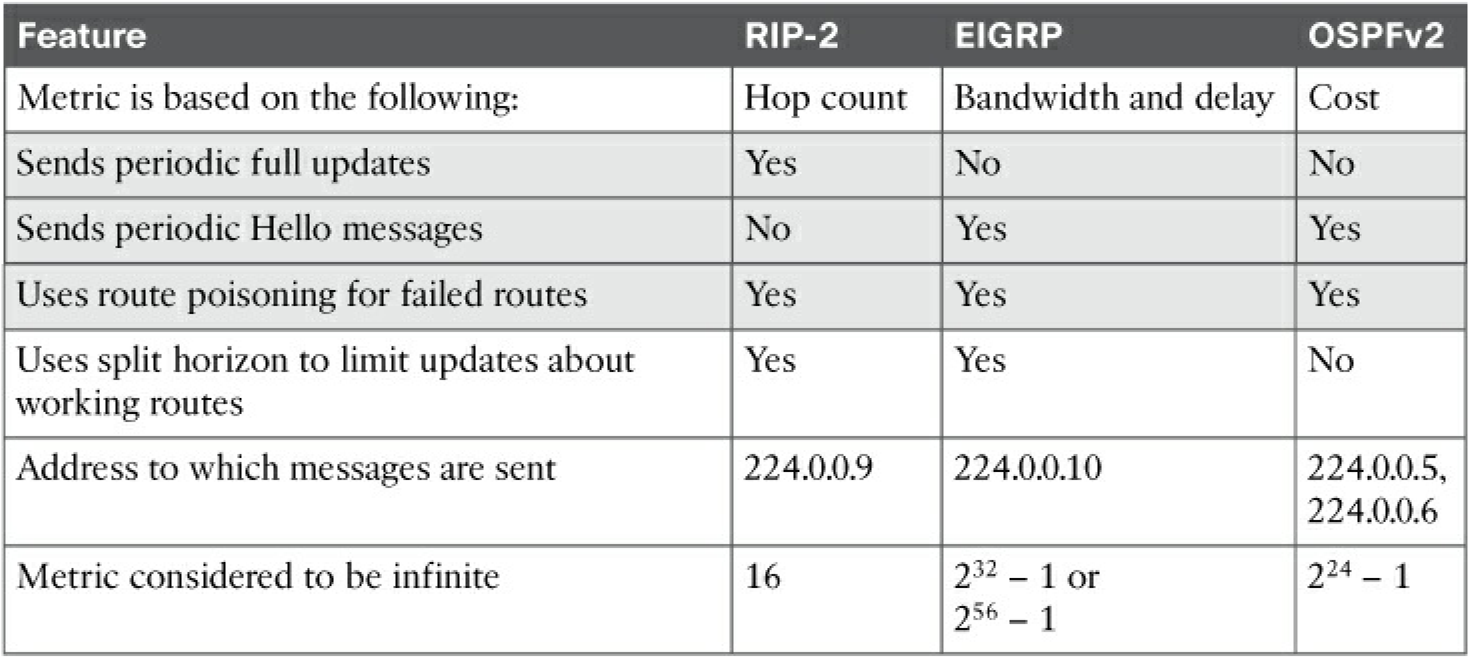
EIGRP does not require two neighboring routers to use the same Hello and hold timers, but it makes good sense to use the same Hello and hold timers on all routers. Unfortunately, the flexibility to use different settings on neighboring routers makes it possible to prevent the neighbors from working properly, just by the poor choice of Hello and hold timers. For instance, if R2 changes its Hello/Hold Intervals to 30/60, respectively, but R1 keeps its Hello/Hold Intervals of 5/15 seconds, R1 will believe R2 has failed on a regular basis. R2 sends Hello messages only every 30 seconds, but R1 expects to receive them within its 15 second Hold Interval.

Summary of Interior Routing Protocol Features

Table 9-3 summarizes the features discussed in this chapter, for RIP-2, EIGRP, and OSPFv2. Following the table, the second major section of this chapter begins, which moves into depth about the specifics of how EIGRP works.

Key Topic

Table 9-3. Interior IP Routing Protocols Compared



Feature	RIP-2	EIGRP	OSPFv2
Metric is based on the following:	Hop count	Bandwidth and delay	Cost
Sends periodic full updates	Yes	No	No
Sends periodic Hello messages	No	Yes	Yes
Uses route poisoning for failed routes	Yes	Yes	Yes
Uses split horizon to limit updates about working routes	Yes	Yes	No
Address to which messages are sent	224.0.0.9	224.0.0.10	224.0.0.5, 224.0.0.6
Metric considered to be infinite	16	$2^{32} - 1$ or $2^{56} - 1$	$2^{24} - 1$

EIGRP Concepts and Operation

EIGRP differs from OSPF in some pretty obvious ways, but in some ways EIGRP acts a lot like OSPF. In fact, EIGRP uses a three-step model similar to OSPF when a router first joins a network. These steps each lead to a list or table: the neighbor table, the topology table, and the routing table. All these processes and tables lead toward building the IPv4 routes in the routing table, as follows:

1. **Neighbor discovery:** EIGRP routers send Hello messages to discover potential neighboring EIGRP routers and perform basic parameter checks to determine which routers should become neighbors. Neighbors that pass all parameter checks are added to the EIGRP neighbor table.
2. **Topology exchange:** Neighbors exchange full topology updates when the neighbor relationship comes up, and then only partial updates as needed based on changes to the network topology. The data learned in these updates is added to the router’s EIGRP topology table.
3. **Choosing routes:** Each router analyzes its respective EIGRP topology tables, choosing the lowest-metric route to reach each subnet. EIGRP places the route with the best metric for each destination into the IPv4 routing table.

This second major section of this chapter discusses the particulars of how EIGRP goes about building its routing table, using these three steps. Although the overall three-step process looks similar to OSPF, the details differ greatly, especially those related to how OSPF uses LS logic to process topology data, whereas EIGRP does not. Also, in addition to these three steps, this section explains some unique logic EIGRP uses when converging and reacting to changes in an internetwork—logic that is not seen with the other types of routing protocols.

EIGRP Neighbors

An EIGRP neighbor is another EIGRP-speaking router, connected to a common subnet, with which the router is willing to exchange EIGRP topology information. EIGRP uses EIGRP Hello messages, sent to multicast IP address 224.0.0.10, to dynamically discover potential neighbors. A router learns of potential neighbors by receiving a Hello.

Routers perform some basic checking of each potential neighbor before that router becomes an EIGRP neighbor. A potential neighbor is a router from which an EIGRP Hello has been received. Then the router checks the following settings to determine whether the router should be allowed to be a neighbor:

Key Topic

- It must pass the authentication process if used.
- It must use the same configured autonomous system number (which is a configuration setting).
- The source IP address used by the neighbor’s Hello must be in the same subnet as the local router’s interface IP address/mask.

Note

The router’s EIGRP K values must also match, but this topic is beyond the scope of this book.

EIGRP uses relatively straightforward verification checks for neighbors. First, if authentication is configured, the two routers must be using the same type of authentication and the same authentication key (password). Second, EIGRP configuration includes a parameter called an *autonomous system number* (ASN), which must be the same on two neighboring routers. Finally, the IP addresses used to send the EIGRP Hello messages—the routers’ respective interface IP addresses—must be in the range of addresses on the other routers’ respective connected subnet.

EIGRP makes the neighbor relationship much simpler than OSPF. Whereas OSPF neighbors have several interim states and a few stable states, EIGRP simply moves to a working state as soon as the neighbor passes the basic verification checks. At that point, the two routers can begin exchanging topology information using EIGRP update messages.

Exchanging EIGRP Topology Information

EIGRP uses EIGRP *update messages* to send topology information to neighbors. These update messages can be sent to multicast IP address 224.0.0.10 if the sending router needs to update multiple routers on the same subnet; otherwise, the updates are sent to the unicast IP address of the particular neighbor. (Hello messages are always sent to the 224.0.0.10 multicast address.) The use of multicast packets on LANs allows EIGRP to exchange routing information with all neighbors on the LAN efficiently.

EIGRP sends update messages without UDP or TCP, but it does use a protocol called *Reliable Transport Protocol* (RTP). RTP provides a mechanism to resend any EIGRP messages that are not received by a neighbor. By using RTP, EIGRP can better avoid loops because a router knows for sure that the neighboring router has received any updated routing information. (The use of RTP is just another example of a difference between basic DV protocols like RIP, which have no mechanism to know whether neighbors receive update messages, and the more advanced EIGRP.)

Note

The acronym RTP also refers to a different protocol, Real-time Transport Protocol (RTP), which is used to transmit voice and video IP packets.

Neighbors use both full routing updates and partial updates A full update means that a router sends information about all known routes, whereas a partial update includes only information about recently changed routes. Full updates occur when neighbors first come up. After that, the neighbors send only partial updates in reaction to changes to a route.

Figure 9-9 summarizes many of the details discussed so far in this section, from top to bottom. It first shows neighbor discovery with Hellos, the sending of full updates, the maintenance of the neighbor relationship with ongoing Hellos, and partial updates.

Key Topic

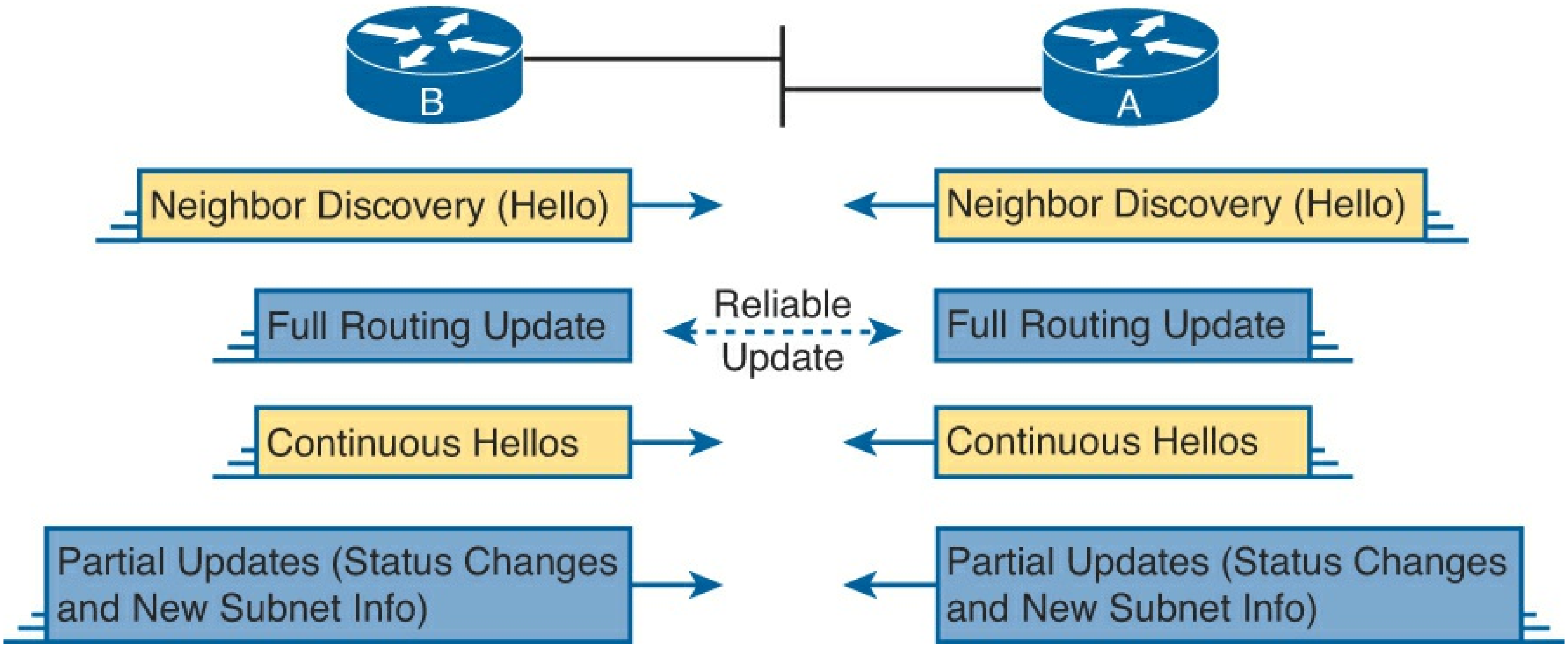

B
A
Neighbor Discovery (Hello)
Neighbor Discovery (Hello)
Full Routing Update
Reliable Update
Full Routing Update
Continuous Hellos
Continuous Hellos
Partial Updates (Status Changes and New Subnet Info)
Partial Updates (Status Changes and New Subnet Info)

Figure 9-9. Full and Partial EIGRP Updates

Note that EIGRP refers to the information exchanged in the updates as topology information. The information is not nearly as detailed as OSPF LS topology data, and it does not attempt to describe every router and link in the network. However, it does describe more than just a distance (metric) and vector (next-hop router) for the local router—a local router also learns the metric as used by the next-hop router. This added information is used to help EIGRP converge quickly, without causing loops, as discussed in the upcoming section "EIGRP Convergence."

Calculating the Best Routes for the Routing Table

EIGRP calculates the metric for routes much differently than any other routing protocol. For instance, with OSPF, anyone with a network diagram and knowledge of the configured OSPF interface costs can calculate the exact OSPF metric (cost) for each route. EIGRP uses a math equation and a composite metric, making the exact metric value hard to predict.

The EIGRP Metric Calculation

The EIGRP composite metric means that EIGRP feeds multiple inputs (called metric components) into the math equation. By default, EIGRP feeds two metric components into the calculation: bandwidth and delay. (EIGRP supports also using the interface load and interface reliability in the metric calculation, although Cisco recommends against using either.) EIGRP also advertises the maximum transmission unit (MTU) associated with the route—that is, the longest IP packet allowed over the route—but does not use the MTU when calculating the metric.

Note

Past documents and books often stated that EIGRP, and its predecessor, IGRP, also could use MTU as a part of the metric, but MTU cannot be used and was never considered as part of the calculation.

EIGRP's metric calculation formula actually helps describe some of the key points about the composite metric. (In real life, you seldom if ever need to sit down and calculate what a router will calculate with this formula.) The formula, assuming that the default settings that tell the router to use just bandwidth and delay, is as follows:

$$\text{Metric} = \left(\left(\frac{10^7}{\text{least-bandwidth}} \right) + \text{cumulative-delay} \right) * 256$$

In this formula, the term *least-bandwidth* represents the lowest-bandwidth link in the route, using a unit of kilobits per second. For instance, if the slowest link in a route is a 10-Mbps Ethernet link, the first part of the formula is 10^7 / 10^4, which equals 1000. You use 10^4 in the formula because 10 Mbps is equal to 10,000 Kbps (10^4 Kbps).

The cumulative-delay value used in the formula is the sum of all the delay values for all outgoing interfaces in the route, with a unit of "tens of microseconds."

Using these two inputs helps EIGRP pick the best route with a little more balance than does OSPF. Using the least bandwidth lets EIGRP avoid routes with the slowest individual links, which are usually the links with the most congestion. At the same time, the delay part of the equation adds the delay for every link, so that routes with a large number of links will be relatively less desirable than a route with fewer links.

You can set both bandwidth and delay for each link, using the cleverly named **bandwidth** and **delay** interface subcommands.

Note

Most **show** commands, including **show ip eigrp topology** and **show interfaces**, list delay settings as the number of microseconds of delay. Note that the EIGRP metric formula uses a unit of tens of microseconds.

An Example of Calculated EIGRP Metrics

Now that you have an idea of how the router's EIGRP math works, next consider an example that connects what a router learns in an EIGRP update message, local configuration settings, and the calculation of the metric for a single route.

A local router must consider the information received from the neighboring router and its local interface settings. First, EIGRP update messages list the subnet number and mask, along with all the metric components: the cumulative delay, minimum bandwidth, along with the other usually unused metric components. The local router then considers the bandwidth and delay settings on the interface on which the update was received, and calculates a new metric.

For example, Figure 9-10 shows router R1 learning about subnet 10.1.3.0/24 from router R2. The EIGRP update message from R2 lists a minimum bandwidth of 100,000 Kbps, and a cumulative delay of 100 microseconds. R1's S0/1 interface has an interface bandwidth set to 1544 Kbps—the default bandwidth on a serial link—and a delay of 20,000 microseconds.

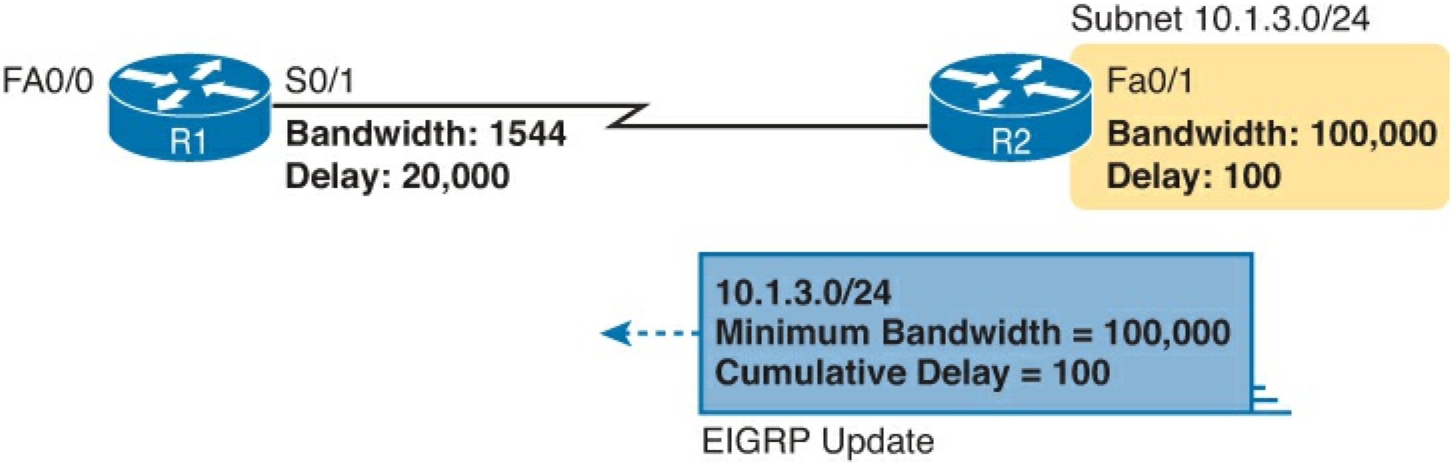


Figure 9-10. How R1 Calculates Its EIGRP Metric for 10.1.3.0/24

Next, consider how R1 thinks about the least bandwidth part of the calculation. R1 discovers that its S0/1 interface bandwidth (1544 Kbps, or 1.544 Mbps) is less than the advertised minimum bandwidth of 100,000 Kbps, or 100 Mbps. R1 needs to use this new, slower bandwidth in the metric calculation. (If R1's S0/1 interface had a bandwidth of 100,000 Kbps or more in this case, R1 would instead use the minimum bandwidth listed in the EIGRP Update from R2.)

As for interface delay, the router always adds its interface delay to the delay listed in the EIGRP Update. However, the unit for delay can be a bit of a challenge. The units, and their use, are as follows:

Unit of microseconds: Listed in the output of **show** commands like **show interfaces** and **show ip eigrp topology**, and in the EIGRP update messages.

Unit of tens-of-microseconds: Used by the interface mode configuration command (**delay**), with which to set the delay, and in the EIGRP metric calculation.

Because of this weird difference in units, when looking at the delay, make sure you keep the units straight. In this particular example:

- R1 received an update that lists delay of 100 (microseconds), which R1 converts to the equivalent 10 tens of microseconds before using it in the formula.
- R1 sees its S0/1 interface setting of 2000 tens of microseconds, so for the purposes of the calculation, R1 adds 10 tens of microseconds for a total delay of 2010 tens of microseconds.

This example results in the following metric calculation:

$$\text{Metric} = \left(\left(\frac{10^7}{1544}\right) + (10 + 2000)\right) * 256 = 2{,}172{,}\ 416$$

Note

For those of you who repeat this math at home, IOS rounds down the division in this formula to the nearest integer before performing the rest of the formula. In this case, 10^7 / 1544 is rounded down to 6476, before adding the 2010 and then multiplying by 256.

If multiple possible routes to subnet 10.1.3.0/24 existed, router R1 also calculates the metric for those routes and chooses the route with the best (lowest) metric to be added to the routing table.

Note

The examples in this chapter show routers with gigabit interfaces, which default their delay settings to 10 microseconds. However, IOS adjusts the delay based on the actual speed of a LAN interface. In the examples in this chapter and the next, all the LAN interfaces happen to run at 100 Mbps, making the delay be 100 microseconds.

Caveats with Bandwidth on Serial Links

EIGRP's robust metric gives it the ability to choose routes that include more router hops but with faster links. However, to ensure that the right routes are chosen, engineers must take care to configure meaningful bandwidth and delay settings. In particular, serial links default to a bandwidth of 1544 and a delay of 20,000 microseconds, as used in the example shown in Figure 9-10. However, IOS cannot automatically change the bandwidth and delay settings based on the Layer 1 speed of a serial link. So, using default bandwidth and delay settings, particularly the bandwidth setting on serial links, can lead to problems.

Figure 9-11 shows the problem with using default bandwidth settings and how EIGRP uses the better (faster) route when the bandwidth is set correctly. The figure focuses on router B's route to subnet 10.1.1.0/24 in each case. In the left side of the figure, all serial interfaces use defaults, even though the top serial link actually runs at a slow 64 Kbps. The right side of the figure shows the results when the slow serial link's **bandwidth** command is changed to reflect the correct (slow) speed.

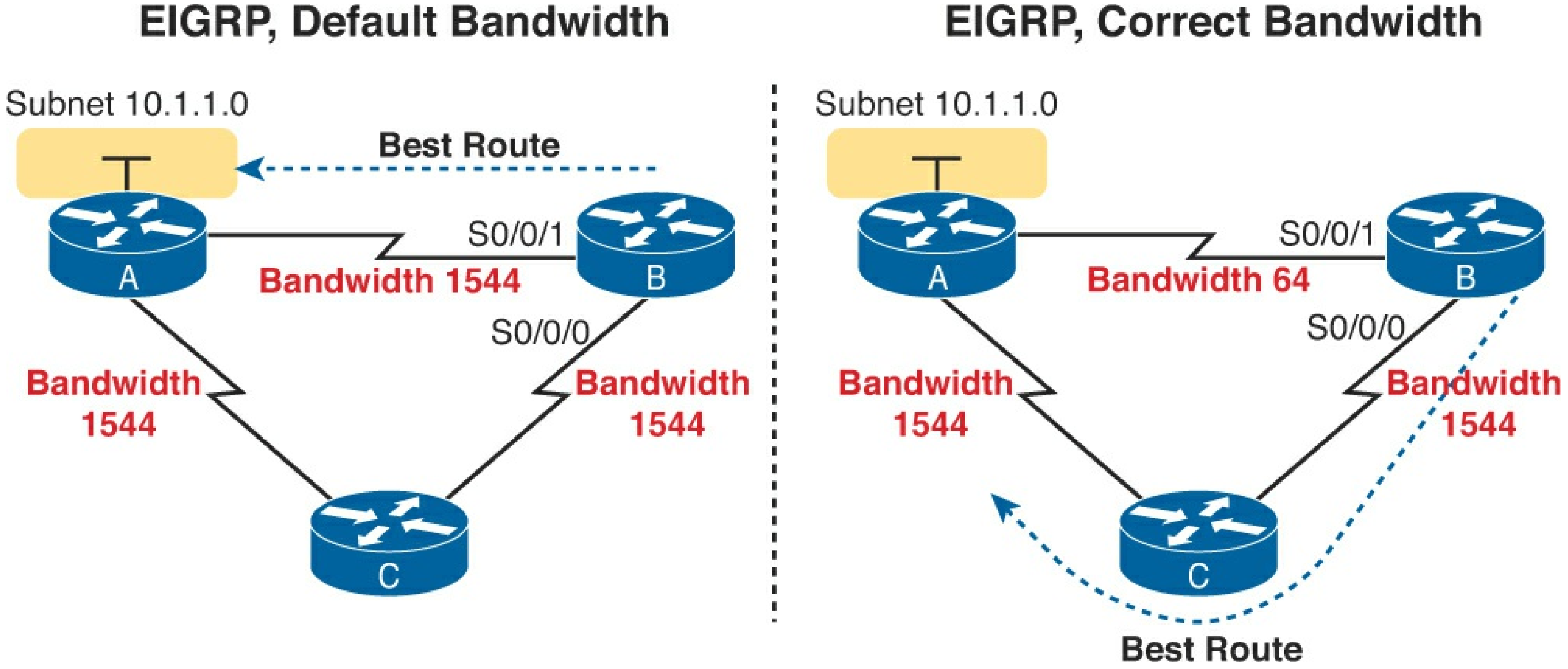


Figure 9-11. Impact of the Bandwidth on EIGRP's Metric Calculation

Generally, a good metric strategy for networks that use EIGRP is to set the WAN bandwidth to match the actual Layer 1 speed, use defaults for LAN interfaces, and EIGRP will usually choose the best routes.

EIGRP Convergence

Now that you have seen the details of how EIGRP forms neighbor relationships, exchanges routing information, and calculates the best route, the rest of this section looks at the most interesting part of EIGRP: EIGRP's work to converge to a new loop-free route.

Loop avoidance poses one of the most difficult problems with any dynamic routing protocol. DV protocols overcome this problem with a variety of tools, some of which create a large portion of the minutes-long convergence time after a link failure. LS protocols overcome this problem by having each router keep a full topology of the network, so by running a rather involved mathematical model, a router can avoid any loops.

EIGRP avoids loops by keeping some basic topological information, while keeping much less information as compared to LS protocols like OSPF. EIGRP keeps a record of each possible next-hop router for alternate routes, and some metric details related to those routes, but no information about the topology beyond the next-hop routers. This sparser topology information does not require the sophisticated shortest path first (SPF) algorithm, but it does allow quick convergence to loop-free routes.

Feasible Distance and Reported Distance

First, before getting into how EIGRP converges, you need to know a few additional EIGRP terms. With EIGRP, a local router needs to consider its own calculated metric for each route, but at the same time, the local router considers the next-hop router's calculated metric for that same destination subnet. And EIGRP has special terms for those metrics, as follows:

Key Topic

- **Feasible Distance (FD):** The local router's metric of the best route to reach a subnet, as calculated on the local router
- **Reported Distance (RD):** The next-hop router's best metric for that same subnet

As usual, the definition makes more sense with an example. Using the same advertisement as in earlier Figure 9-10, Figure 9-12 shows the two calculations done by R1. One calculation finds R1's own metric (FD) for its one route for subnet 10.1.3.0/24, as discussed around Figure 9-10. The other uses the metric components in the update received from R2, to calculate what R2 would have calculated for R2's metric to reach this same subnet. R1's second calculation based on R2's information—a slowest bandwidth of 100,000 Kbps and a cumulative delay of 100 microseconds—is R1's RD for this route.

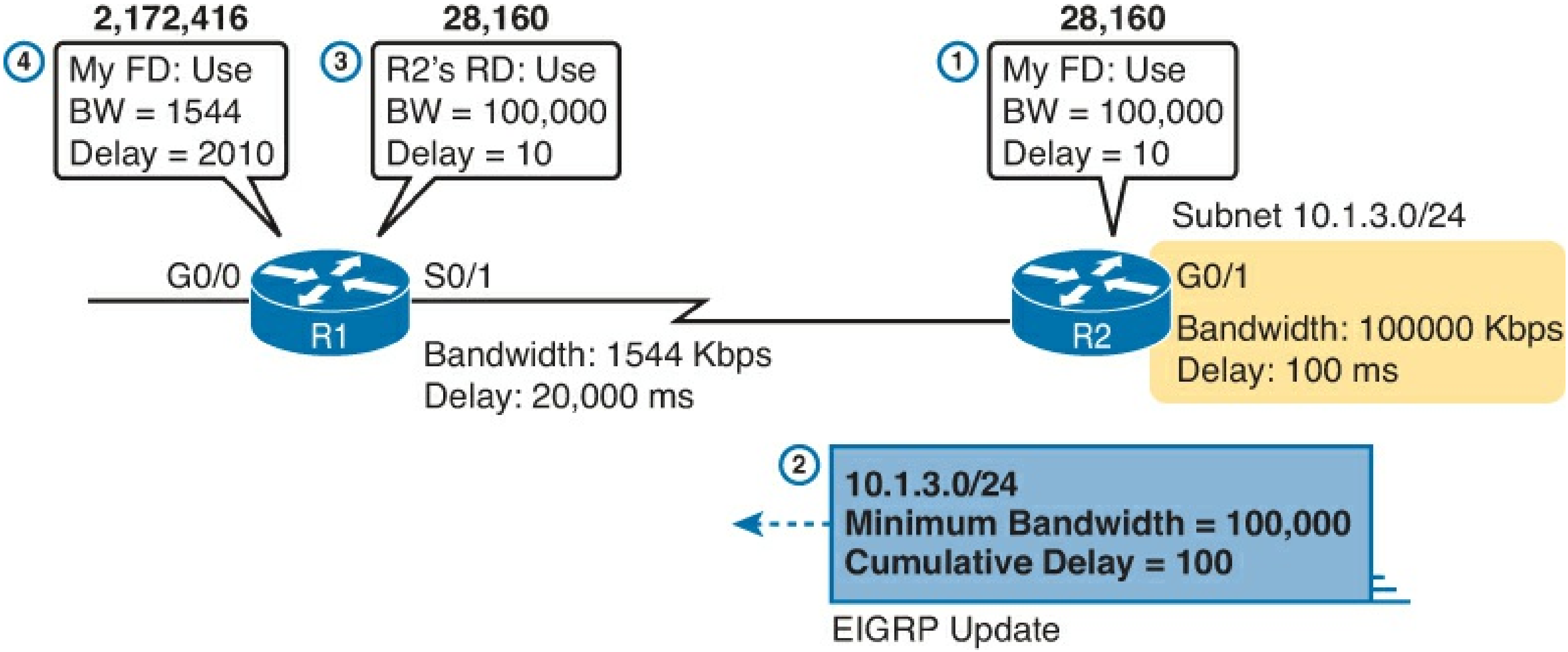


Figure 9-12. How R1 Calculates RD and FD for 10.1.3.0/24

Following the steps in the figure:

1. R2 calculates its own metric (its FD) for R2's route for 10.1.3.0/24, based on a bandwidth of 100,000 Kbps and a delay of 100 microseconds.
2. R2 sends the EIGRP update that lists 10.1.3.0/24, with these same metric components.
3. R1 calculates the RD for this route, using the same math R2 used at Step 1, using the information in the update message from Step 2.
4. R1 calculates its own metric, from R1's perspective, by considering the bandwidth and delay of R1's S0/1 interface, as discussed earlier around Figure 9-10.

In fact, based on the information in Figure 9-12, R2's FD to reach subnet 10.1.3.0/24, which is also R1's RD to reach 10.1.3.0/24, could be easily calculated:

$$\left(\left(\frac{10^7}{100,000}\right) + (10)\right) * 256 = 28,160$$

The EIGRP convergence process uses one of two branches in its logic, based on whether the failed route does or does not have a *feasible successor* route. The decision of whether a router has a feasible successor route depends on the FD and RD values of the competing routes to reach a given subnet. The next topic defines this concept of a feasible successor route and discusses what happens in that case.

EIGRP Successors and Feasible Successors

EIGRP calculates the metric for each route to reach each subnet. For a particular subnet, the route with the best metric is called the successor, with the router filling the IP routing table with this successor route. (This successor route's metric is called the feasible distance, as introduced earlier.)

Of the other routes to reach that same subnet—routes whose metrics were larger than the FD for the successor route—EIGRP needs to determine which alternate route can be used immediately if the currently best route fails, without causing a routing loop. EIGRP runs a simple algorithm to identify which routes could be used, keeping these loop-free backup routes in its topology table and using them if the currently best route fails. These alternative, immediately usable routes are called *feasible successor* routes because they can feasibly be used as the new successor route when the previous successor route fails.

A router determines whether a route is a feasible successor based on the feasibility condition:

Key Topic

If a nonsuccessor route's RD is less than the FD, the route is a feasible successor route.

Although it is technically correct, this definition is much more understandable with an example. Figure 9-13 begins an example in which router E chooses its best route to subnet 1. Router E learns three routes to subnet 1, from Routers B, C, and D. The figure shows the metrics as calculated on router E, as listed in router E's EIGRP topology table. Router E finds that the route through Router D has the lowest metric, making that route E's successor route for subnet 1. Router E adds that route to its routing table, as shown. The FD is the metric calculated for this route, a value of 14,000 in this case.

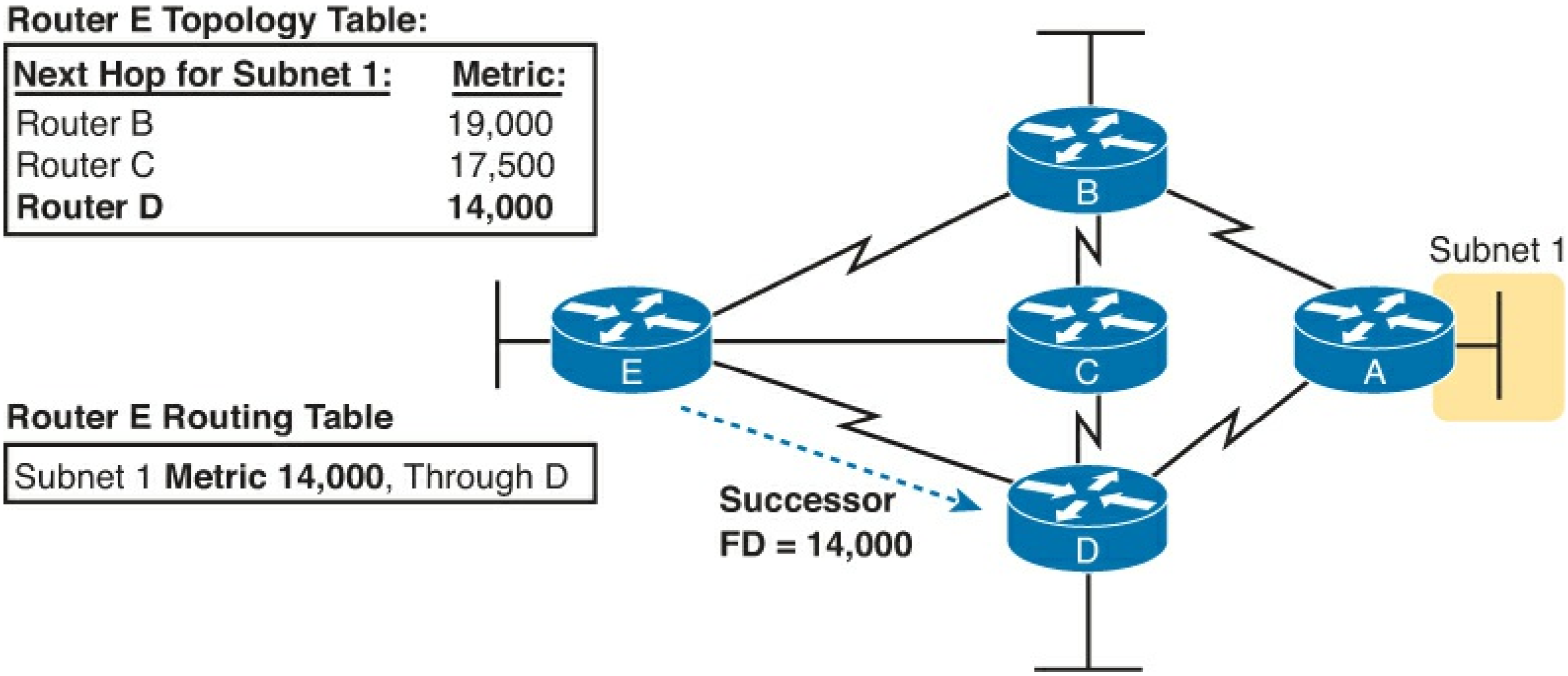

Router E Topology Table:
Next Hop for Subnet 1: Metric:
Router B 19,000
Router C 17,500
Router D 14,000
Router E Routing Table
Subnet 1 Metric 14,000, Through D
Successor
FD = 14,000
B
C
A
E
D
Subnet 1

Figure 9-13. Route Through Router D is the Successor Route to Subnet 1

At the same time, EIGRP on router E decides whether either of the other two routes to subnet 1 can be used immediately if the route through router D fails for whatever reason. Only a feasible successor route can be used. To meet the feasibility condition, the alternate route's RD must be less than the FD of the successor route. Figure 9-14 shows an updated version of Figure 9-13. Router E uses the following logic to determine that the route through router B is not a feasible successor route, but the route through router C is, as follows:

- Router E compares the FD of 14,000 to the RD of the route through B (19,000). The RD is worse than the FD, so this route is not a feasible successor.
- Router E compares the FD of 14,000 to the RD of the route through C (13,000). The RD is better than the FD, making this route a feasible successor.

Key Topic

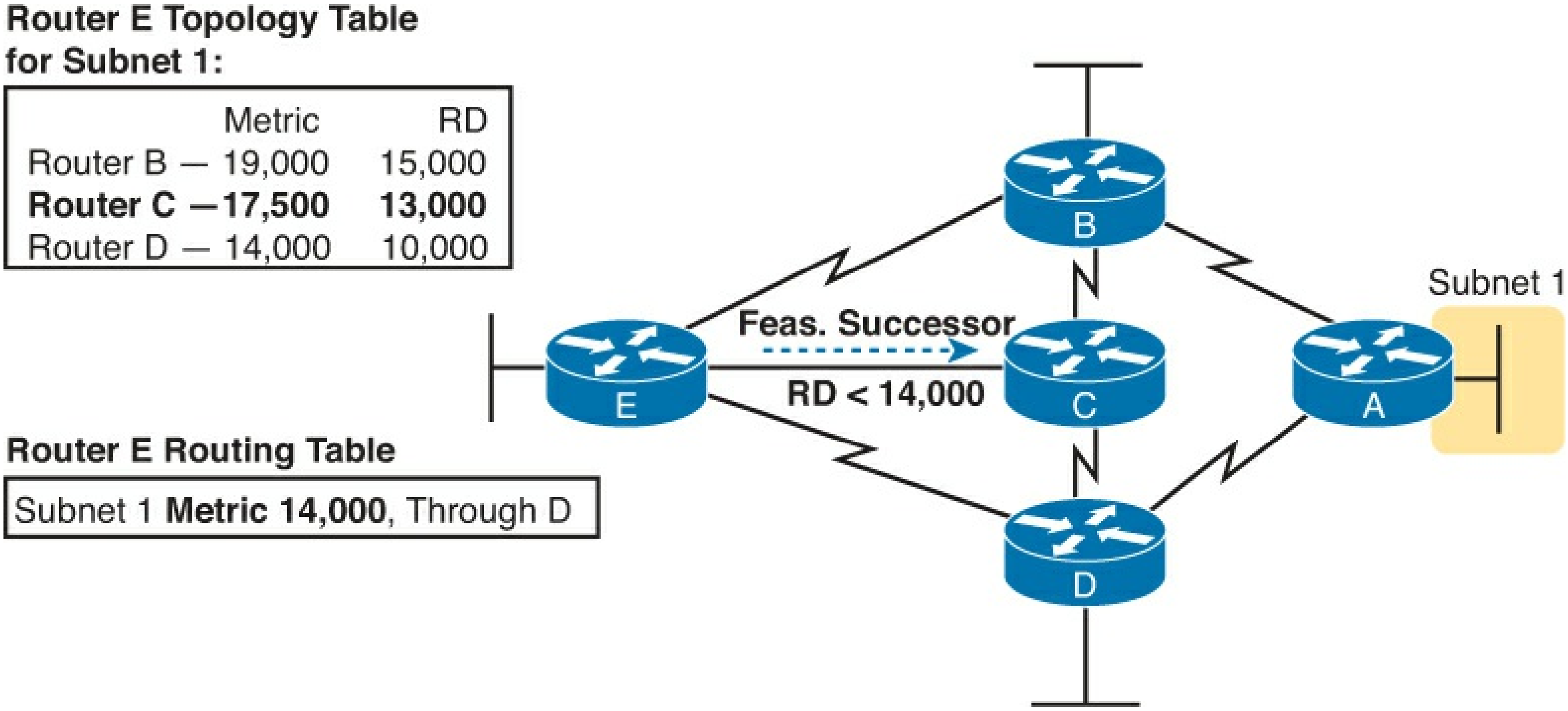

Router E Topology Table for Subnet 1:
Metric RD
Router B — 19,000 15,000
Router C —17,500 13,000
Router D — 14,000 10,000
Router E Routing Table
Subnet 1 Metric 14,000, Through D
Feas. Successor
RD < 14,000
B
C
A
E
D
Subnet 1

Figure 9-14. Route Through Router C Is a Feasible Successor

If the route to subnet 1 through router D fails, Router E can immediately put the route through router C into the routing table without fear of creating a loop. Convergence occurs almost instantly in this case.

The Query and Reply Process

When a route fails, and the route has no feasible successor, EIGRP uses a distributed algorithm called *Diffusing Update Algorithm* (DUAL) to choose a replacement route. DUAL sends queries looking for a loop-free route to the subnet in question. When the new route is found, DUAL adds it to the routing table.

The EIGRP DUAL process simply uses messages to confirm that a route exists, and would not create a loop, before deciding to replace a failed route with an alternative route. For instance, in Figure 9-14, imagine that both Routers C and D fail. Router E does not have any remaining feasible successor route for subnet 1, but there is an obvious physically available path through Router B. To use the route, Router E sends EIGRP *query* messages to its working neighbors (in this case, Router B). Router B’s route to subnet 1 is still working fine, so router B replies to Router E with an EIGRP *reply* message, simply stating the details of the working route to subnet 1 and confirming that it is still viable. Router E can then add a new route to subnet 1 to its routing table, without fear of a loop.

Replacing a failed route with a feasible successor takes a very short amount of time, usually less than a second or two. When queries and replies are required, convergence can take slightly longer, but in most networks, convergence can still occur in less than 10 seconds.

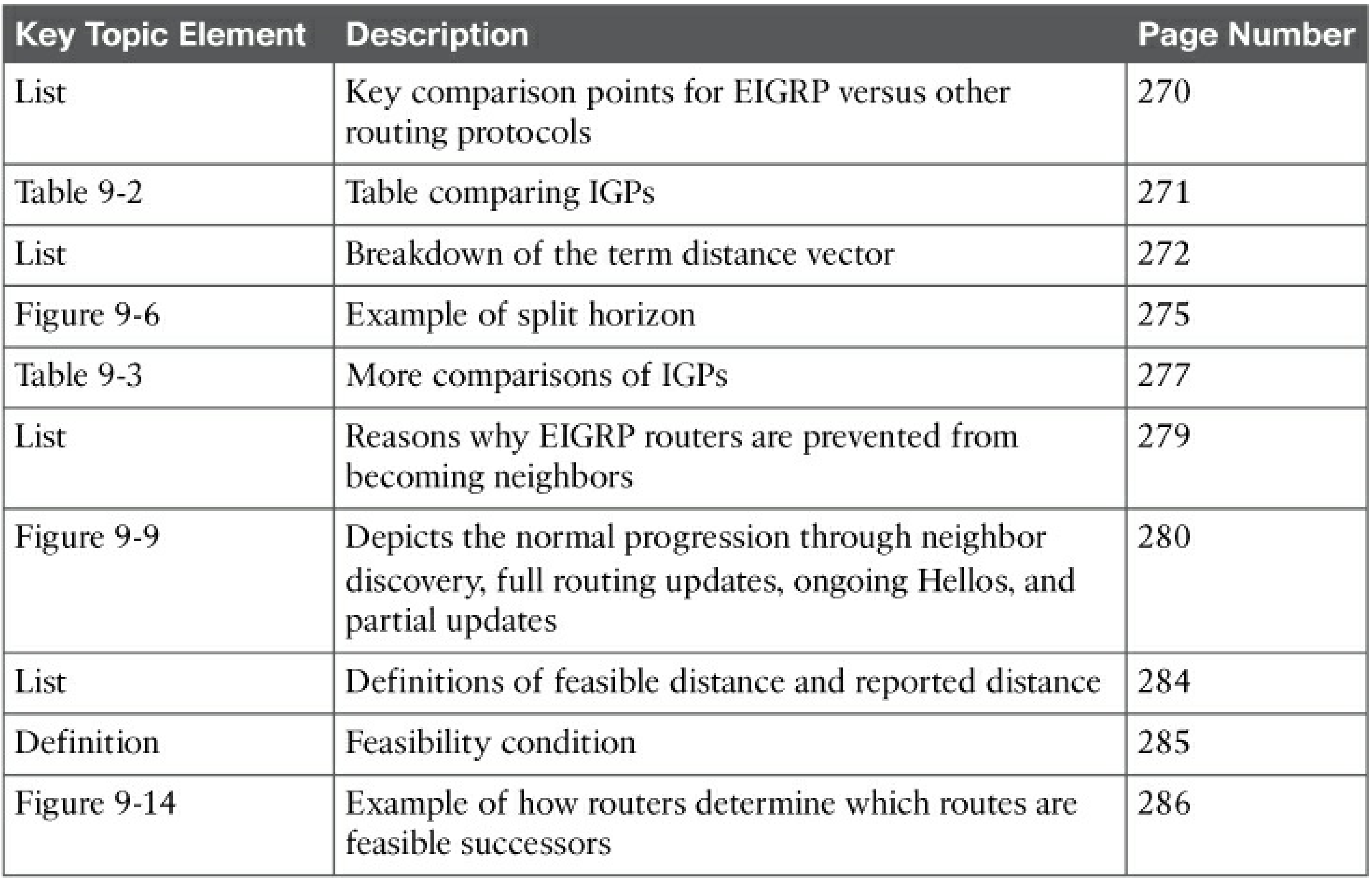
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 9-4 lists these key topics and where each is discussed.

Key Topic

Table 9-4. Key Topics for Chapter 9



Key Topic Element	Description	Page Number
List	Key comparison points for EIGRP versus other routing protocols	270
Table 9-2	Table comparing IGPs	271
List	Breakdown of the term distance vector	272
Figure 9-6	Example of split horizon	275
Table 9-3	More comparisons of IGPs	277
List	Reasons why EIGRP routers are prevented from becoming neighbors	279
Figure 9-9	Depicts the normal progression through neighbor discovery, full routing updates, ongoing Hellos, and partial updates	280
List	Definitions of feasible distance and reported distance	284
Definition	Feasibility condition	285
Figure 9-14	Example of how routers determine which routes are feasible successors	286

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix D, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix E, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22 directs you in how to use these terms for late-stage preparation for the exam.

convergence
distance vector
interior gateway protocol (IGP)
partial update
poison reverse
poisoned route
split horizon
triggered update
feasibility condition
feasible distance
feasible successor
full update
reported distance
successor

Chapter 10. Implementing EIGRP for IPv4

This chapter covers the following exam topics:

IP Routing Technologies

Configure and verify EIGRP (single AS)
- Feasible distance *feasible successors* administrative distance
- Feasibility condition
- Metric composition
- Router ID
- Auto summary
- Path selection
- Load balancing
  - Equal
  - Unequal
- Passive interface

Differentiate methods of routing and routing protocols
- administrative distance
- split horizon
- metric
- next hop

Whereas the preceding chapter looked solely at Enhanced Interior Gateway Routing Protocol (EIGRP) concepts, this chapter looks at the details of making it work in a Cisco router.

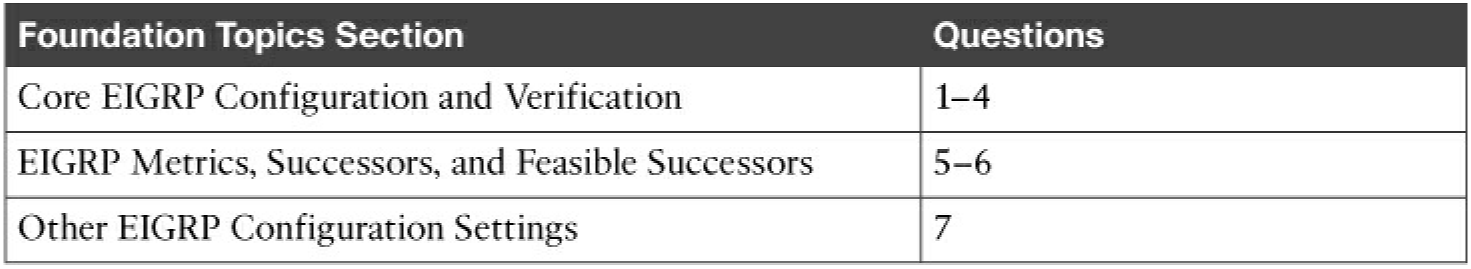
This chapter works through a variety of EIGRP configuration options. It starts with the most fundamental EIGRP configuration options. This chapter also works through a few less-common configuration tasks, such as how to configure unequal-metric load balancing, as well as the autosummary feature, which might sound great, but which today is mostly a potential area for causing problems.

Throughout this chapter, the text moves back and forth between the configuration and the related commands to verify that the configured feature is working. In particular, this chapter takes a careful look at how to look for the feasible distance, reported distance, and find the successor and feasible successor routes.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the Exam Preparation Tasks section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 10-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Core EIGRP Configuration and Verification	1–4
EIGRP Metrics, Successors, and Feasible Successors	5–6
Other EIGRP Configuration Settings	7

1. Which of the following **network** commands, following the command **router eigrp 1**, tells this router to start using EIGRP on interfaces whose IP addresses are 10.1.1.1, 10.1.100.1, and 10.1.120.1? (Choose two answers.)

   a. network 10.0.0.0

   b. network 10.1.1x.0

   c. network 10.0.0.0 0.255.255.255

   d. network 10.0.0.0 255.255.255.0

2. Routers R1 and R2 attach to the same VLAN with IP addresses 10.0.0.1 and 10.0.0.2, respectively. R1 is configured with the commands **router eigrp 99** and **network 10.0.0.0.** Which of the following commands might be part of a working EIGRP configuration on R2 that ensures that the two routers become neighbors and exchange routes? (Choose two answers.)

   a. network 10

   b. network 10.0.0.1 0.0.0.0

   c. network 10.0.0.2 0.0.0.0

d. network 10.0.0.0

3. In the **show ip route** command, what code designation implies that a route was learned with EIGRP?

   a. E

   b. I

   c. G

   d. D

4. Examine the following excerpt from a **show** command on router R1:

Click here to view code image

```
EIGRP-IPv4 Neighbors for AS(1)
H Address Interface Hold Uptime SRTT RTO Q Seq
(sec) (ms) Cnt Num
1 10.1.4.3 Se0/0/1 13 00:05:49 2 100 0 29
0 10.1.5.2 Se0/0/0 12 00:05:49 2 100 0 39
```

Which of the following answers is true about this router based on this output?

a. Address 10.1.4.3 identifies a working neighbor based on that neighbor's current EIGRP router ID.

b. Address 10.1.5.2 identifies a router that may or may not become an EIGRP neighbor at some point after both routers check all neighbor requirements.

c. Address 10.1.5.2 identifies a working neighbor based on that neighbor's interface IP address on the link between R1 and that neighbor.

d. Address 10.1.4.3 identifies R1's own IP address on interface S0/0/1.

5. Examine the following excerpt from a router's CLI:

Click here to view code image

```
P 10.1.1.0/24, 1 successors, FD is 2172416
via 10.1.6.3 (2172416/28160), Serial0/1
via 10.1.4.2 (2684416/2284156), Serial0/0
via 10.1.5.4 (2684416/2165432), Serial1/0
```

Which of the following identifies a next-hop IP address on a feasible successor route?

a. 10.1.6.3

b. 10.1.4.2

c. 10.1.5.4

d. It cannot be determined from this command output.

6. Router R1's EIGRP process knows of three possible routes to subnet 1. One route is a successor, and one is a feasible successor. R1 is not using the **variance** command to allow for unequal cost load balancing. Which of the following commands happen to show information about the feasible successor route, including its metric, whether as EIGRP topology information or as an IPv4 route?

   a. show ip eigrp topology

   b. show ip eigrp database

   c. show ip route eigrp

   d. show ip eigrp interfaces

7. Router R1 has four routes to subnet 2. The one successor route has a metric of 100, and the one feasible successor route has a metric of 350. The other routes have metrics of 450 and 550. R1's EIGRP configuration includes the **variance 5** command. Choose the answer that refers to the highest-metric route to subnet 2 that will be visible in the output of the **show ip route eigrp** command on R1.

   a. The successor route (metric 100)

   b. The feasible successor route (metric 350)

   c. The route with metric 450

   d. The route with metric 550

Answers to the "Do I Know This Already?" quiz:

1 A and C **2** C and D **3** D **4** C **5** C **6** A **7** B

Foundation Topics

Core EIGRP Configuration and Verification

This first of three major sections of the chapter starts the discussion of EIGRP by showing the most commonly used parts of EIGRP configuration. As is usual with this book's implementation chapters, this section begins with configuration topics, followed by verification.

EIGRP Configuration

EIGRP configuration closely resembles OSPF configuration. The **router eigrp** command enables EIGRP and puts the user in EIGRP configuration mode, in which one or more **network** commands are configured. For each interface matched by a **network** command, EIGRP tries to discover neighbors on that interface, and EIGRP advertises the subnet connected to the interface.

The following configuration checklist outlines the main configuration tasks covered in this chapter:

Key Topic

Step 1. Enter EIGRP configuration mode and define the EIGRP autonomous system number (ASN) by using the **router eigrp** *as-number* global command.

Step 2. Configure one or more **network** *ip-address* [*wildcard-mask*] router subcommands. This enables EIGRP on any matched interface and causes EIGRP to advertise the connected subnet.

Step 3. (Optional) Set the EIGRP router ID (RID) explicitly with the **eigrp router-id** *value* router subcommand.

Step 4. (Optional) Change the interface Hello and hold timers using the **ip hello-interval eigrp** *asn time* and **ip hold-time eigrp** *asn time* interface subcommands.

Step 5. (Optional) Impact metric calculations by tuning bandwidth and delay using the **bandwidth** *value* and **delay** *value* interface subcommands.

Step 6. (Optional) Configure support for multiple equal-cost routes using the **maximum-paths** *number* and **variance** *multiplier* router subcommands.

Step 7. (Optional) Enable automatic summarization of routes at the boundaries of classful IPv4 networks using the **autosummary** router subcommand.

Example 10-1 begins the configuration discussion with the simplest possible EIGRP configuration. This configuration uses as many defaults as possible, but it does enable EIGRP on each router on all the interfaces shown in Figure 10-1. All three routers can use the exact same configuration, with only two commands required on each router.

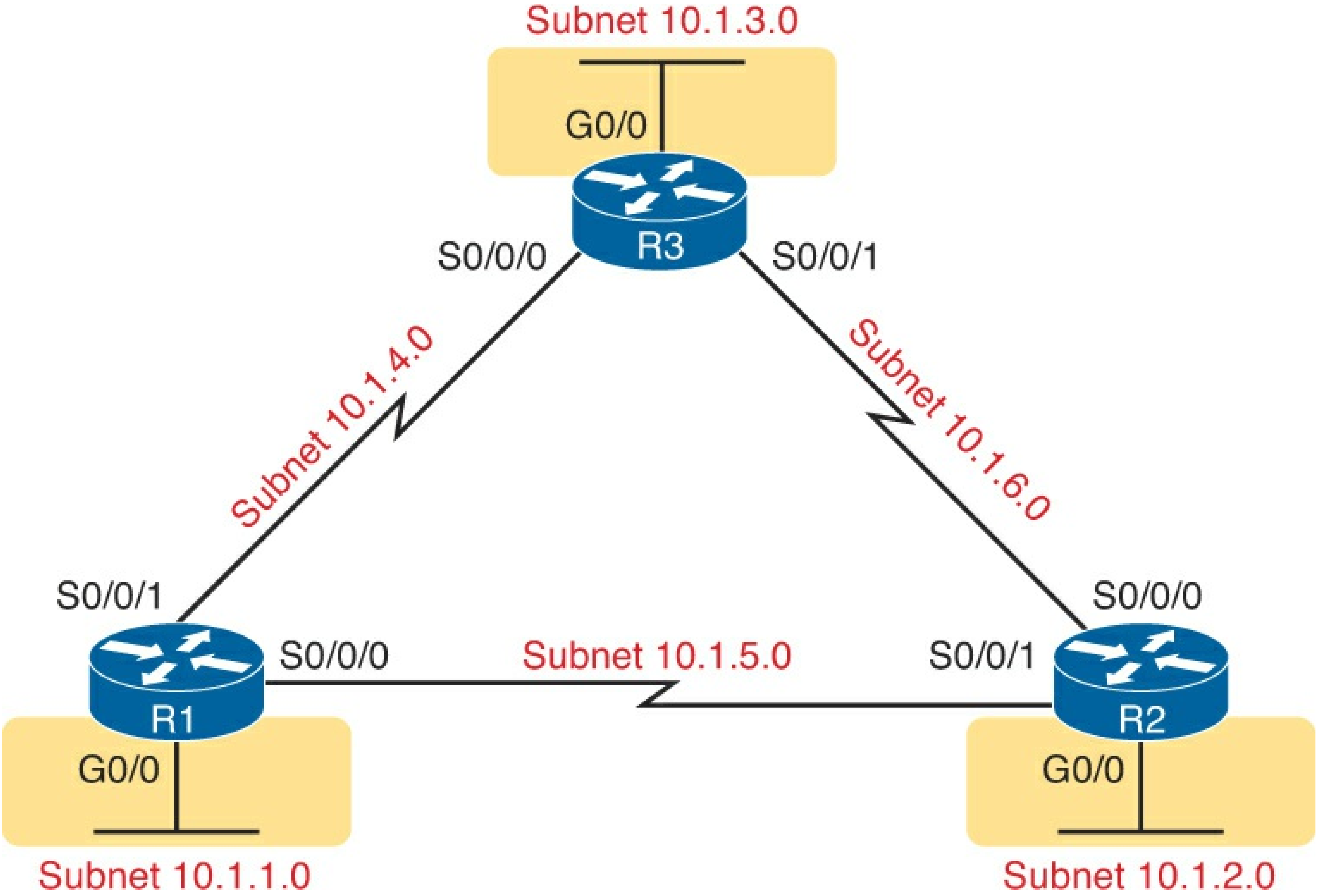


Figure 10-1. Sample Internetwork Used in Most of the EIGRP Examples

Example 10-1. EIGRP Configuration on All Three Routers in Figure 10-1

```
router eigrp 1
network 10.0.0.0
```

This simple configuration only uses two parameters that the network engineer must choose: the autonomous system number and the classful network number in the **network** command.

The actual ASN does not matter, but all the routers must use the same ASN in the **router eigrp** command. For instance, they all use **router eigrp 1** in this example. (Routers that use different ASNs will not become EIGRP neighbors.) The range of valid ASNs is 1 through 65,535, which is the same range of valid process IDs with the **router ospf** command.

The EIGRP **network** commands allows two syntax options: one with a wildcard mask at the end and one without, as shown with Example 10-1's **network 10.0.0.0** command. With no wildcard mask listed, this command must list a classful network (a Class A, B, or C network number). Once configured, this command tells the router to do the following:

- Look for that router's own interfaces with addresses in that classful network
- Enable EIGRP on those interfaces

Once enabled, EIGRP starts advertising about the subnet connected to an interface. It also starts sending Hello messages and listening for incoming Hello messages, trying to form neighbor relationships with other EIGRP routers.

Note

Interestingly, on real routers, you can type an EIGRP **network** *number* command and use a dotted-decimal number that is not a classful network number; in that case, IOS does not issue an error message. However, IOS changes the number you typed to be the classful network number in which that number resides. For example, IOS changes the **network 10.1.1.1** command to **network 10.0.0.0**.

Configuring EIGRP Using a Wildcard Mask

The EIGRP **network** command syntax without the wildcard mask, as shown in Example 10-1, may be exactly what an engineer wants to use, but it also might prove a bit clumsy. For instance, if an engineer wants to enable EIGRP on G0/0, and not on G0/1, and they both have IP addresses in Class A network 10.0.0.0, the **network 10.0.0.0** EIGRP subcommand would match both interfaces, instead of just G0/0.

IOS has a second option for the EIGRP **network** command that uses a wildcard mask so that the engineer can match exactly the correct interface IP addresses intended. In this case, the **network** command does not have to list a classful **network** number. Instead, IOS matches an interface IP address that would be matched if the address and wildcard mask in the **network** command were part of an access control list (ACL). The logic works just like an ACL address and wildcard mask, and just like the address/mask logic in the OSPF **network** commands discussed in Chapter 8, "Implementing OSPF for IPv4."

For example, looking back at Figure 10-1, router R3 has IP addresses in three subnets: 10.1.3.0/24, 10.1.4.0/24, and 10.1.6.0/24. Example 10-2 shows an alternate EIGRP configuration for router R3 that uses a **network** command to match the range of addresses in each subnet for R3's three connected subnets. With a subnet mask of /24, each of the **network** commands uses a wildcard mask of 0.0.0.255, with an address parameter of the subnet ID off one of R3's interfaces.

Example 10-2. Using Wildcard Masks with EIGRP Configuration

Click here to view code image

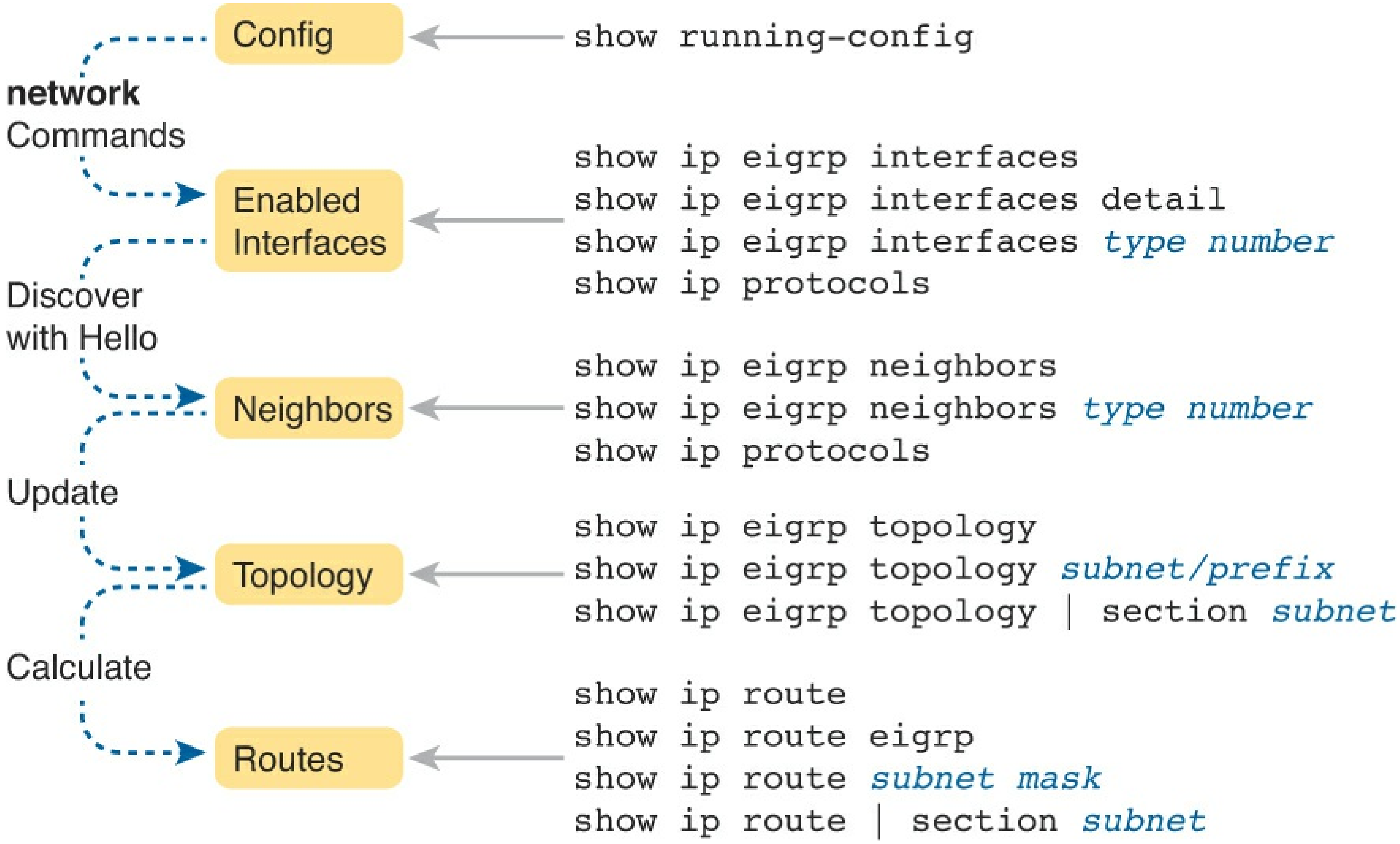
```
R3(config)# router eigrp 1
R3(config-router)# network 10.1.3.0 0.0.0.255
R3(config-router)# network 10.1.4.0 0.0.0.255
R3(config-router)# network 10.1.6.0 0.0.0.255
```

Alternatively, R3 could have matched each interface with commands that use a wildcard mask of 0.0.0.0, listing the specific IP address of each interface. For instance, the **network 10.1.3.3 0.0.0.0** command would match R3's LAN interface address of 10.1.3.3, enabling EIGRP on that one interface.

Verifying EIGRP Core Features

Like OSPF, EIGRP uses three tables to match its three major blocks of logic: a neighbor table, a topology table, and the IPv4 routing table. But before EIGRP even attempts to build these tables, IOS must connect the configuration logic to its local interfaces. Once enabled on an interface, a router can then start to build its three tables.

The next several pages walk through the verification steps to confirm a working internetwork that uses EIGRP. Figure 10-2 shows the progression of concepts from top to bottom on the left, with a reference for the various **show** commands on the right. The topics to follow use that same sequence.



```
show running-config

show ip eigrp interfaces
show ip eigrp interfaces detail
show ip eigrp interfaces type number
show ip protocols

show ip eigrp neighbors
show ip eigrp neighbors type number
show ip protocols

show ip eigrp topology
show ip eigrp topology subnet/prefix
show ip eigrp topology | section subnet

show ip route
show ip route eigrp
show ip route subnet mask
show ip route | section subnet
```

Figure 10-2. Roadmap of Topics (Left) and Verification Commands (Right)

> **Note**
>
> All the upcoming verification examples list output taken from the routers in Figure 10-1. From that figure, routers R1 and R2 use the EIGRP configuration Example 10-1, and router R3 uses the configuration shown in

Example 10-2. Also, note that all routers use gigabit LAN interfaces, but run at 100 Mbps due to their connections to the switches; this fact impacts the metrics to a small degree.

Finding the Interfaces on Which EIGRP is Enabled

First, each router must enable EIGRP on the correct interfaces. Example 10-3 begins the verification process by connecting the configuration to the router interfaces on which EIGRP is enabled. IOS gives us three ways to find the list of interfaces:

- Use **show running-config** to look at the EIGRP and interface configuration, and apply the same logic as EIGRP to find the list of interfaces on which EIGRP should be enabled.
- Use **show ip protocols** to list a shorthand version of the EIGRP configuration, to again apply the same logic as EIGRP and predict the list of interfaces.
- Use **show ip eigrp interfaces** to list the interfaces on which the router has actually enabled EIGRP.

Of these three options, only the **show ip eigrp interfaces** command gives us the true list of interfaces as actually chosen by the router. The other two methods give us the configuration, and let us make an educated guess. (Both are important!)

The **show ip eigrp interfaces** command lists EIGRP-enabled interfaces directly, and briefly, with one line per interface. Alternatively, the **show ip eigrp interfaces detail** command lists much more detail per interface, including the Hello and Hold Intervals, as well as noting whether split horizon is enabled. Example 10-3 shows an example of both from router R1.

Example 10-3. Looking for Interfaces on Which EIGRP Has Been Enabled on R1

Click here to view code image

```
R1# show ip eigrp interfaces
EIGRP-IPv4 Interfaces for AS(1)
Xmit Queue PeerQ Mean Pacing Time Multicast Pending
Interface Peers Un/Reliable Un/Reliable SRTT Un/Reliable Flow Timer Routes
Gi0/0 0 0/0 0/0 0 0/0 0 0
Se0/0/0 1 0/0 0/0 2 0/16 50 0
Se0/0/1 1 0/0 0/0 1 0/15 50 0

R1# show ip eigrp interfaces detail S0/0/0
EIGRP-IPv4 Interfaces for AS(1)
Xmit Queue PeerQ Mean Pacing Time Multicast Pending
Interface Peers Un/Reliable Un/Reliable SRTT Un/Reliable Flow Timer Routes
Se0/0/0 1 0/0 0/0 2 0/16 50 0
Hello-interval is 5, Hold-time is 15
Split-horizon is enabled
! lines omitted for brevity
```

Note that the first command, **show ip eigrp interfaces,** lists all interfaces for which EIGRP is enabled and for which the router is currently sending Hello messages trying to find new EIGRP neighbors. R1, with a single **network 10.0.0.0** EIGRP subcommand, enables EIGRP on all three of its interfaces (per Figure 10-1). The second command lists more detail per interface, including the local router's own Hello interval and hold time and the split-horizon setting.

Note that neither command lists information about interfaces on which EIGRP is not enabled. For instance, had EIGRP not been enabled on S0/0/0, the **show ip eigrp interfaces detail S0/0/0** command would have simply listed no information under the heading lines. The shorter output of the **show ip eigrp interface** command omits interfaces on which EIGRP is not enabled.

Also, note that the **show ip eigrp interfaces...** command does not list information for passive interfaces. Like Open Shortest Path First (OSPF), EIGRP supports the **passive-interface** *type number* subcommand. This command tells EIGRP to not discover and form neighbor relationships on the listed interface. However, EIGRP still advertises about the subnet connected to the interface.

In summary, the **show ip eigrp interfaces** command lists information about interfaces enabled by EIGRP, but it does not list interfaces made passive for EIGRP.

The other two methods to find the EIGRP-enabled interfaces require an examination of the configuration and some thinking about the EIGRP rules. In real life, **show ip eigrp interfaces** is the place to start, but for the exam, you might have just the configuration, or you might not even have that. As an alternative, the **show ip protocols** command lists many details about EIGRP, including a shorthand repeat of the EIGRP **network** configuration commands. Example 10-4 lists these commands as gathered from router R1.

Example 10-4. Using show ip protocols **to Derive the List of EIGRP-Enabled Interfaces on R1**

Click here to view code image

```
R1# show ip protocols
*** IP Routing is NSF aware ***
```

```
Routing Protocol is "eigrp 1"
Outgoing update filter list for all interfaces is not set
Incoming update filter list for all interfaces is not set
Default networks flagged in outgoing updates
Default networks accepted from incoming updates
EIGRP-IPv4 Protocol for AS(1)
Metric weight K1=1, K2=0, K3=1, K4=0, K5=0
NSF-aware route hold timer is 240
Router-ID: 10.1.5.1
Topology : 0 (base)
Active Timer: 3 min
Distance: internal 90 external 170
Maximum path: 4
Maximum hopcount 100
Maximum metric variance 1

Automatic Summarization: disabled
Maximum path: 4
Routing for Networks:
10.0.0.0
Routing Information Sources:
Gateway Distance Last Update
10.1.4.3 90 00:22:32
10.1.5.2 90 00:22:32
Distance: internal 90 external 170
```

To see the shorthand repeat of the EIGRP configuration, look toward the end of the example, for under the heading Routing for Networks. In this case, the next line that lists 10.0.0.0 is a direct reference to the **network 10.0.0.0** configuration command shown in Example 10-1. For configurations that use the wildcard mask option, the format differs a little, as shown in Example 10-5, which shows an excerpt of the **show ip protocols** command from R3. R3 uses the three **network** commands shown earlier in Example 10-2.

Key Topic

Example 10-5. Seeing the Configured network **Commands with** show ip protocols

Click here to view code image

```
R3# show ip protocols
! Lines omitted for brevity

Automatic Summarization: disabled
Maximum path: 4
Routing for Networks:
10.1.3.0/24
10.1.4.0/24
10.1.6.0/24
! Lines omitted for brevity
```

To interpret the meaning of the highlighted portions of this **show ip protocols** command, you have to do a little math. The output lists a number in the format of *x (in this case,* 24). It represents a wildcard mask with x binary 0s, or in this case, 0.0.0.255.

Before moving on from the **show ip protocols** command, take a moment to read some of the other details of this command's output from Example 10-5. For instance, it lists the EIGRP router ID (RID), which for R1 is 10.1.5.1. EIGRP allocates its RID just like OSPF, based on the following:

Key Topic

1. The value configured with the **eigrp router-id** *number* EIGRP subcommand
2. The numerically highest IP address of an up/up loopback interface at the time the EIGRP process comes up
3. The numerically highest IP address of a nonloopback interface at the time the EIGRP process comes up

The only difference compared to OSPF is that the EIGRP RID is configured with the **eigrp router-id** *value* router subcommand, whereas OSPF uses the **router-id** *value* subcommand.

Displaying EIGRP Neighbor Status

Once a router has enabled EIGRP on an interface, the router tries to discover neighboring routers by listening for EIGRP Hello messages. If two neighboring routers hear Hellos from each other and the required parameters match correctly, the routers become neighbors.

The best and most obvious command to list EIGRP neighbors is **show ip eigrp neighbors**. This command lists neighbors based on their interface IP address (and not based on their router ID, which is the convention with OSPF). The output also lists the local router's interface out which the neighbor is reachable.

For instance, Example 10-6 shows router R1's neighbors, listing a neighbor with IP address 10.1.4.3 (R3). It is reachable from R1's S0/0/1 interface according to the first highlighted line in the example.

Example 10-6. Displaying EIGRP Neighbors from Router R1

Click here to view code image

```
R1# show ip eigrp neighbors
EIGRP-IPv4 Neighbors for AS(1)
H Address Interface Hold Uptime SRTT RTO Q Seq
(sec) (ms) Cnt Num
1 10.1.4.3 Se0/0/1 13 00:05:49 2 100 0 29
0 10.1.5.2 Se0/0/0 12 00:05:49 2 100 0 39
```

The right side of the output also lists some interesting statistics. The four rightmost columns have to do with RTP, as discussed back in Chapter 9, "Understanding EIGRP Concepts." The uptime lists the elapsed time since the neighbor relationship started. Finally, the hold time should be the current countdown from the Hold Interval (15 seconds in this case) down toward 0. In this case, with a Hello Interval of 5 and a Hold Interval of 15, this counter will vary from 15 down to 10 and then reset to 15 when the next Hello arrives.

Another less-obvious way to list EIGRP neighbors is the **show ip protocols** command. Look back again to Example 10-4, to the end of the **show ip protocols** command output from R1. That output under the heading Routing Information Sources lists the same two neighboring routers' IP addresses, as does the **show ip eigrp neighbors** command in Example 10-6.

Displaying the IPv4 Routing Table

Once EIGRP routers become neighbors, they exchange routing information, store it in their topology tables, and then they calculate their best IPv4 routes. This section skips past the verification steps for the EIGRP topology table, saving that for the second major topic in the chapter, as an end to itself. However, you should find the IP routing table verification steps somewhat familiar at this point. Example 10-7 shows a couple of examples from R1 in Figure 10-1: The first showing the entire IPv4 routing table and with the **show ip route eigrp** command at the end listing only EIGRP-learned routes.

Example 10-7. IP Routing Table on Router R1 from Figure 10-1

Click here to view code image

```
R1# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
E1 - OSPF external type 1, E2 - OSPF external type 2
i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
ia - IS-IS inter area, * - candidate default, U - per-user static route
o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
+ - replicated route, % - next hop override

Gateway of last resort is not set

10.0.0.0/8 is variably subnetted, 9 subnets, 2 masks
C 10.1.1.0/24 is directly connected, GigabitEthernet0/0
L 10.1.1.1/32 is directly connected, GigabitEthernet0/0
D 10.1.2.0/24 [90/2172416] via 10.1.5.2, 00:06:39, Serial0/0/0
D 10.1.3.0/24 [90/2172416] via 10.1.4.3, 00:00:06, Serial0/0/1
C 10.1.4.0/24 is directly connected, Serial0/0/1
L 10.1.4.1/32 is directly connected, Serial0/0/1
C 10.1.5.0/24 is directly connected, Serial0/0/0
L 10.1.5.1/32 is directly connected, Serial0/0/0
D 10.1.6.0/24 [90/2681856] via 10.1.5.2, 00:12:20, Serial0/0/0
[90/2681856] via 10.1.4.3, 00:12:20, Serial0/0/1
```

```
R1# show ip route eigrp
! Legend omitted for brevity

10.0.0.0/8 is variably subnetted, 9 subnets, 2 masks
D 10.1.2.0/24 [90/2172416] via 10.1.5.2, 00:06:43, Serial0/0/0
D 10.1.3.0/24 [90/2172416] via 10.1.4.3, 00:00:10, Serial0/0/1
D 10.1.6.0/24 [90/2681856] via 10.1.5.2, 00:12:24, Serial0/0/0
[90/2681856] via 10.1.4.3, 00:12:24, Serial0/0/1
```

The **show ip route** and **show ip route eigrp** commands both list the EIGRP-learned routes with a D beside them. Cisco chose to use D to represent EIGRP because when EIGRP was created, the letter E was already being used for a now-extinct Exterior Gateway Protocol (EGP) routing protocol. Cisco chose the next-closest unused letter, D, to denote EIGRP-learned routes.

Next, take a moment to think about the EIGRP routes learned by R1 versus R1's connected routes. Six subnets exist in the design in Figure 10-1: three on the LANs, and three on the WANs. The first command in the example lists three of these subnets as connected routes (10.1.1.0/24, 10.1.4.0/24, and 10.1.5.0/24). The other three subnets appear as EIGRP-learned routes.

Finally, note that the two numbers in brackets for each route list the administrative distance and the composite metric, respectively. IOS uses the administrative distance to choose the better route when IOS learns multiple routes for the same subnet but from two different sources of routing information. Refer back to Chapter 8's "Administrative Distance" section for a review.

EIGRP Metrics, Successors, and Feasible Successors

Both OSPF and EIGRP use similar big ideas: enabling the protocol on the routers interfaces, forming neighbor relationships, building topology tables, and adding IPv4 routes to the routing table. These two routing protocols differ most in the topology data they create and use. As a link-state protocol, OSPF creates and saves a lot of topology data, enough data to model the entire network topology in an area. EIGRP saves different kinds of data, in less detail, and uses a completely different algorithm to analyze the data.

This second major section in this chapter focuses on the details of the EIGRP topology database and specifically on the key ideas stored in the database. To review, as defined in Chapter 9, an EIGRP successor route is a router's best route to reach a subnet. Any of the other possible loop-free routes that can be used if the successor route fails is called a feasible successor (FS) route. And all the information used to determine which route is the successor, FS, or neither, sits inside the EIGRP topology table.

This section demonstrates how to use **show** commands to identify successor routes and FS routes by looking at the EIGRP topology table. To make the discussion more interesting, the examples in this section use an expanded sample network, as shown in Figure 10-3.

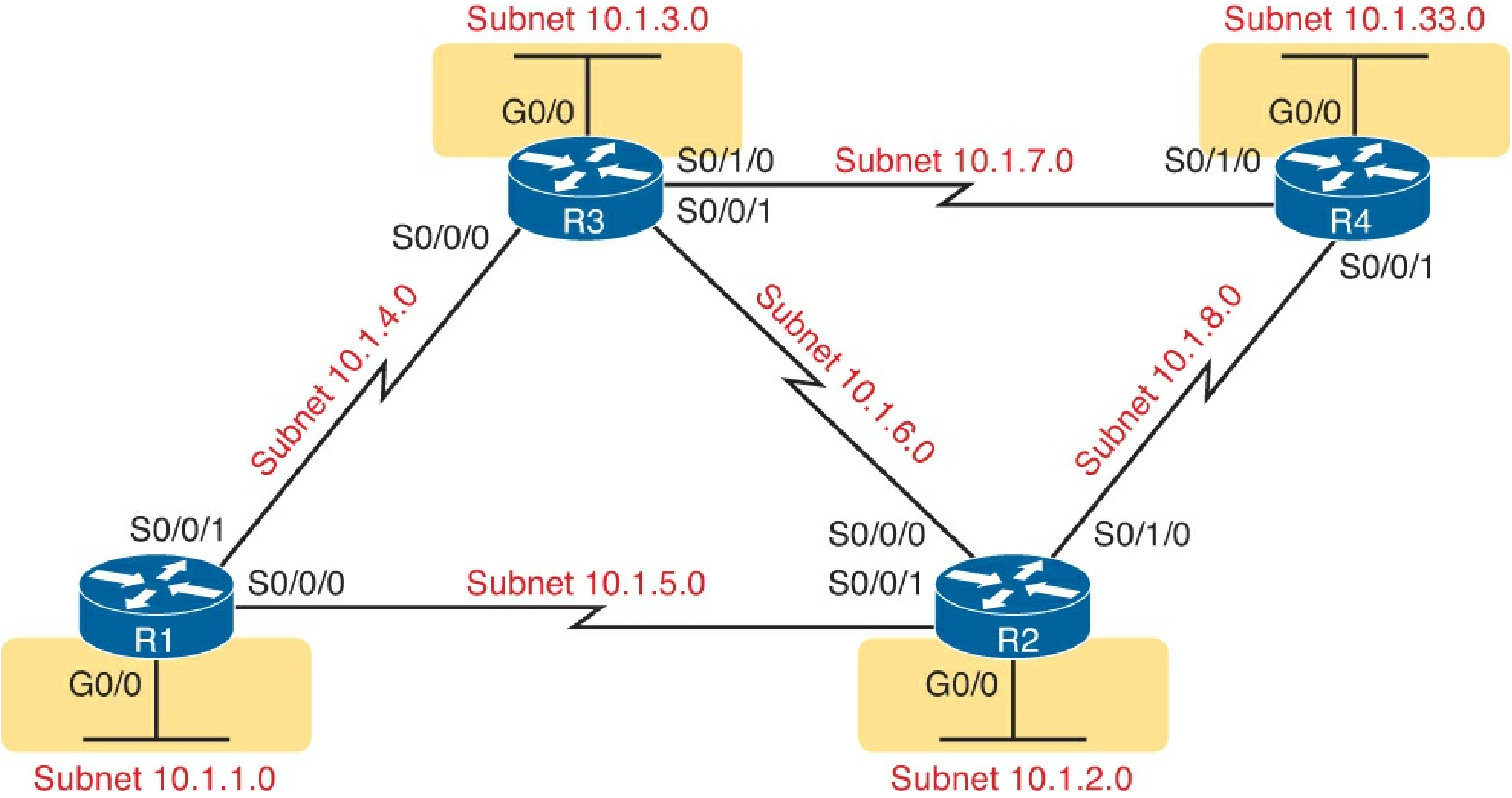


Figure 10-3. Expanded Sample Internetwork

Viewing the EIGRP Topology Table

To begin, first consider the EIGRP topology table in router R1, with this expanded network of Figure 10-3. The new network has five WAN and four LAN subnets, with multiple routes to reach each subnet. All the links use default bandwidth and delay settings. (Like the earlier examples, note that all router Gigabit interfaces happen to autonegotiate to use a speed of 100 Mbps, which changes the interface delay setting and therefore the EIGRP metric calculations.)

Example 10-8 begins the discussion with the output of the **show ip eigrp topology** command from R1. This command lists a few lines of information about each known subnet in R1's EIGRP topology table.

Example 10-8. The EIGRP Topology Table on Router R1

Click here to view code image

```
R1# show ip eigrp topology
EIGRP-IPv4 Topology Table for AS(1)/ID(10.1.5.1)
Codes: P - Passive, A - Active, U - Update, Q - Query, R - Reply,
r - reply Status, s - sia Status

P 10.1.5.0/24, 1 successors, FD is 2169856
via Connected, Serial0/0/0
P 10.1.7.0/24, 1 successors, FD is 2681856
via 10.1.4.3 (2681856/2169856), Serial0/0/1
P 10.1.3.0/24, 1 successors, FD is 2172416
via 10.1.4.3 (2172416/28160), Serial0/0/1
P 10.1.2.0/24, 1 successors, FD is 2172416
via 10.1.5.2 (2172416/28160), Serial0/0/0
P 10.1.6.0/24, 2 successors, FD is 2681856
via 10.1.4.3 (2681856/2169856), Serial0/0/1
via 10.1.5.2 (2681856/2169856), Serial0/0/0
P 10.1.4.0/24, 1 successors, FD is 2169856
via Connected, Serial0/0/1
P 10.1.33.0/24, 2 successors, FD is 2684416
via 10.1.4.3 (2684416/2172416), Serial0/0/1
via 10.1.5.2 (2684416/2172416), Serial0/0/0
P 10.1.1.0/24, 1 successors, FD is 28160
via Connected, GigabitEthernet0/0
P 10.1.8.0/24, 1 successors, FD is 2681856
via 10.1.5.2 (2681856/2169856), Serial0/0/0
```

First, look through all the output, and count the subnets, in the lines that align with the left edge of the example. Note that R1 lists a group of messages for all nine subnets, including the connected subnets off R1. EIGRP keeps its topology information about all the subnets, even the connected subnets.

Next, focus on the first highlighted entry, for subnet 10.1.3.0/24, the subnet off R3's LAN interface. The first line for a given subnet lists the subnet ID and mask. It also lists the number of successor routes, and the feasible distance (FD). (As a reminder, the FD is the metric of the successor route, which is the best route to reach a particular subnet.)

To help make sure the items are clear, Figure 10-4 breaks down these items, using these same details about subnet 10.1.3.0/24 from R1's EIGRP topology table.

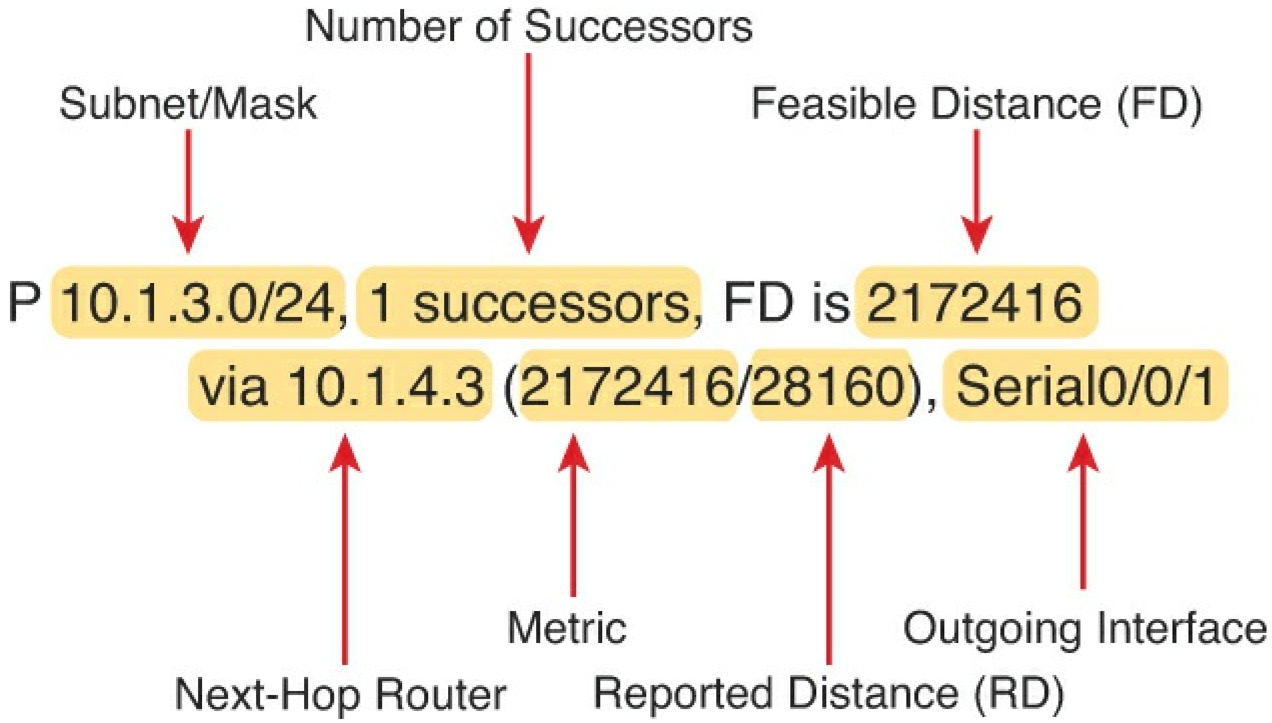


Figure 10-4. Reference to Fields in the Output from show ip eigrp topology

Continuing to focus on subnet 10.1.3.0/24 for a few more moments, the output lists one line per destination subnet and then one line per route below it, indented, beginning with the word *via*. In Figure 10-4, the main line (as usual) lists the subnet, prefix mask, the number of successor routes, and the FD. The second (indented) line lists information about the route, with the next-hop router (after the word *via*), and the outgoing interface. If the router puts this particular route into the IP routing table, the IP route would use this next-hop IP address and local outgoing interface in that route. Note that if EIGRP can list multiple such lines that begin with via if EIGRP has multiple possible routes for that subnet.

Finally, note that the **show ip eigrp topology** command also lists two calculated EIGRP metrics in parentheses. The first is the metric as calculated by the local router for that route. The second is the reported distance (RD): the metric calculated from the perspective of the next-hop router. In the example shown in Figure 10-4, the RD of 28,160 is R1's RD for that route, which is the metric on next-hop router 10.1.4.3 (R3).

Finding Successor Routes

Unfortunately, the **show ip eigrp topology** command does not make it obvious which routes are successor (in other words, best) routes and which ones are feasible successor (in other words, quickly used loop-free replacement) routes. The next few pages walk through how to look at the data in the output of this command and identify the successor and FS routes.

First, for perspective, note that the output in Example 10-8 happens to list only successor routes, with no feasible successor routes. With all default bandwidth and delay settings, no routes qualify as feasible successor routes in this network. Upcoming Example 10-11 changes some settings, causing some routes to have feasible successors. For now, just note that all routes listed in Example 10-8 are successor routes.

The best way to recognize successor routes is that the successor route has the same metric value as the FD. The first line of topology output for a subnet lists the FD (that is, the best metric among all the routes to reach that destination subnet). The successor route, by definition, has the best metric, so the successor route's metric should equal the FD. As shown in Figure 10-5, just look for the FD on the first line and then for the individual routes that have the same metric in the first number inside parentheses.

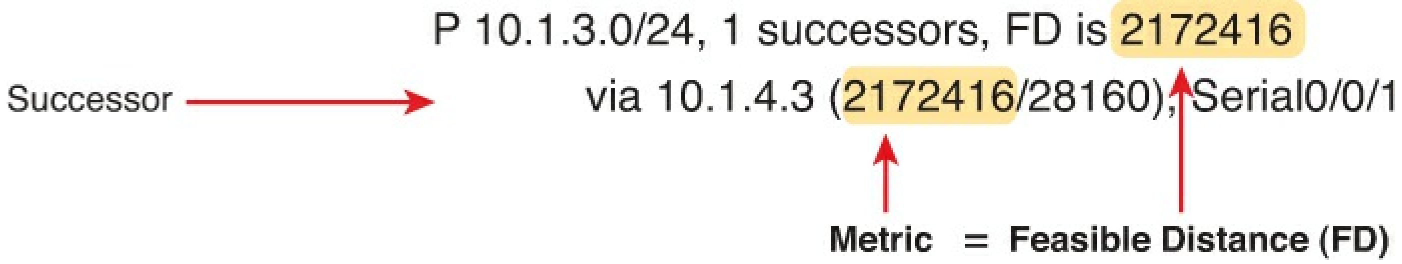

P 10.1.3.0/24, 1 successors, FD is 2172416
Successor
via 10.1.4.3 (2172416/28160), Serial0/0/1
Metric = Feasible Distance (FD)

Figure 10-5. Identifying the Successor: FD (First Line) = Metric (Second Line)

When EIGRP calculates the metrics for all possible routes, sometimes one clear winner exists, so EIGRP chooses one successor route (as shown in Figure 10-5). However, in other cases, the metrics for competing routes for the same subnet tie. In that case, with default EIGRP configuration settings, EIGRP supports a feature called *equal-cost load balancing*, which tells EIGRP to treat all the routes that tie as successor routes.

Example 10-9 shows two successor routes. The example shows an excerpt of the R1 EIGRP topology table for R1's route to subnet 10.1.33.0/24. That subnet exists off R4's LAN interface. In this case, R1 lists two routes, out two different interfaces to two different neighboring next-hop routers. Both routes list the same metric, which matches the FD (2,684,416), so both are successor routes.

Example 10-9. Displaying Two Successor Routes on R1 for Subnet 10.1.33.0/24

Click here to view code image

```
R1# show ip eigrp topology | section 10.1.33.0
P 10.1.33.0/24, 2 successors, FD is 2684416
via 10.1.4.3 (2684416/2172416), Serial0/0/1
via 10.1.5.2 (2684416/2172416), Serial0/0/0
```

In this case, with default settings, R1 would add both routes to its IP routing table. Later in this chapter, the section "EIGRP Maximum Paths and Variance" discusses some similar logic of how a router deals with somewhat equal-cost routes to the same subnet. That section also gives a little more insight into the equal-cost load-balancing option.

Note

The command in Example 10-9 pipes the output of the **show ip eigrp topology** command to the **section** command. This process asks IOS to find a section or group of messages with the listed text (in this case, 10.1.33.0) and display only that group of messages. It is just a way to getting the desired subset of the output without listing the entire command.

Finding Feasible Successor Routes

By convention, the **show ip eigrp topology** lists both successor and feasible successor routes when both exist. The examples so far in this chapter, which used all default bandwidth and delay settings, simply did not happen to result in any FS routes. The next topic changes the configuration, creating a FS route, and then shows how to recognize this route in the topology database.

First, consider Example 10-9's listing of R1's topology data for subnet 10.1.33.0/24, the LAN subnet off R4. From R1's perspective, with all default bandwidth and delay settings, two routes are as identical as they can be. The route from R1 through R3 uses two serial links with default settings for bandwidth of 1544 Kbps and delay of 20,000 microseconds on all the serial links. The route from R1 through R2 also uses two serial links, also with default bandwidth and delay. As a result, R1 has the two equal-cost routes for subnet 10.1.33.0/24, as shown on the left side of Figure 10-6.

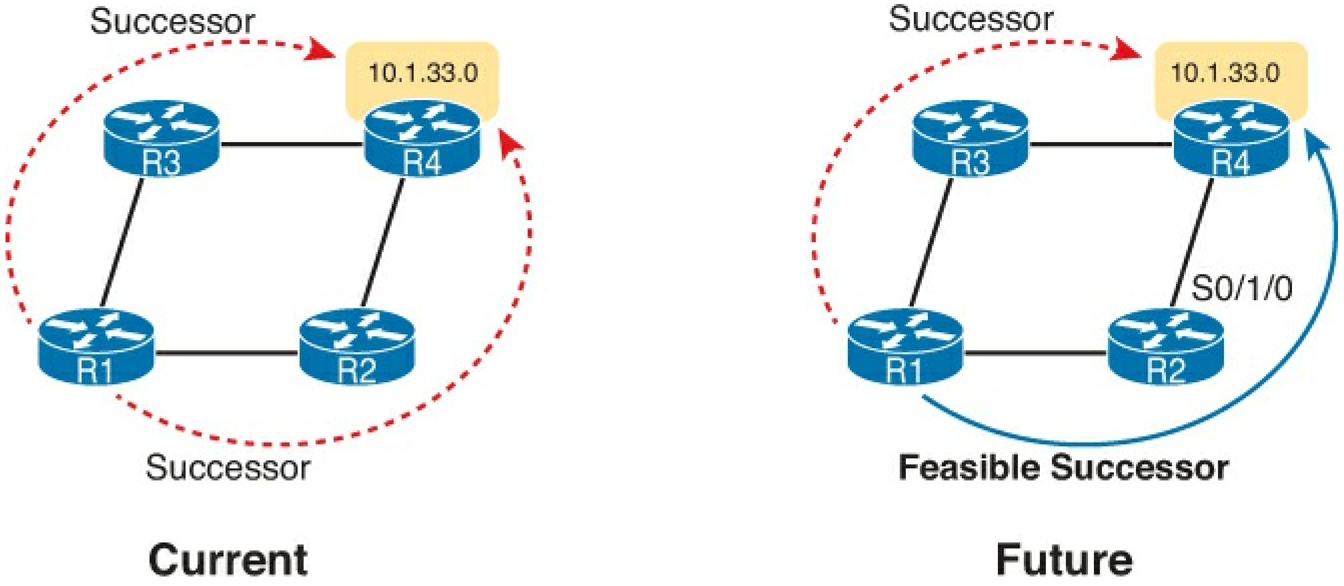


Figure 10-6. Comparing Two Successor Routes to One Successor and One FS

The next example makes the route through R2 worse than the route through R3, by simply lowering the bandwidth on R2's serial link connected to R4. Currently, the path R1-R2-R4 has, from R1's perspective, a slowest bandwidth of 1544 Kbps. By lowering the bandwidth to some other number lower than 1544 Kbps, the metrics of the two routes will no longer exactly tie. A slightly lower bandwidth will result in the upper R1-R3-R4 route being the only successor route, with the R1-R2-R4 route being a FS route.

First, to change the configuration to use a worse (slower) slowest bandwidth, Example 10-10 shows R2's S0/1/0 configuration being changed with the **bandwidth 1400** command.

Example 10-10. Tuning EIGRP Routes by Changing Interface Bandwidth

Click here to view code image

```
R2# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R2(config)# interface s0/1/0
R2(config-if)# bandwidth 1400
```

As soon as R2 changes its bandwidth, R2 sends a partial EIGRP update, as discussed back in Chapter 9. The other routers learn some new information, and they recalculate their own metrics, and the RD values, as appropriate. To see the differences, Example 10-11 repeats the **show ip eigrp topology | section 10.1.33.0** command on R1, as last seen in Example 10-9. In Example 10-9, that command showed R1 with two successor routes for this subnet. Now, in Example 10-11, R1 has only 1 successor route, but with the FS actually hidden there in the output, as explained after the example.

Example 10-11. Viewing a Feasible Successor Route on R1 for 10.1.33.0/24

Click here to view code image

```
R1# show ip eigrp topology | section 10.1.33.0
P 10.1.33.0/24, 1 successors, FD is 2684416
via 10.1.4.3 (2684416/2172416), Serial0/0/1
via 10.1.5.2 (2854912/2342912), Serial0/0/0
```

To see the feasible successor route, and why it is an FS, work through the various numbers in the output in Example 10-11. Or, work through that same output, repeated in Figure 10-7, with notes. In either case, the logic works like the notes in this list:

- Per the first line, one successor route exists.
- The FD is 2,684,416.
- Of the two lines that begin with via—the two possible routes listed—the first route's metric of 2,684,416 equals the FD. As a result, this first line lists the details of the one successor route.
- The other line that begins with via has a metric (first number in parentheses) of 2,854,912, which differs from the FD value of 2,684,416. As a result, this route is not a successor route.
- The second line that begins with via has a reported distance (RD, the second number) of 2,342,912, which is less than the FD of 2,684,416. This second route meets the feasibility condition, making it a feasible successor route.

Key Topic

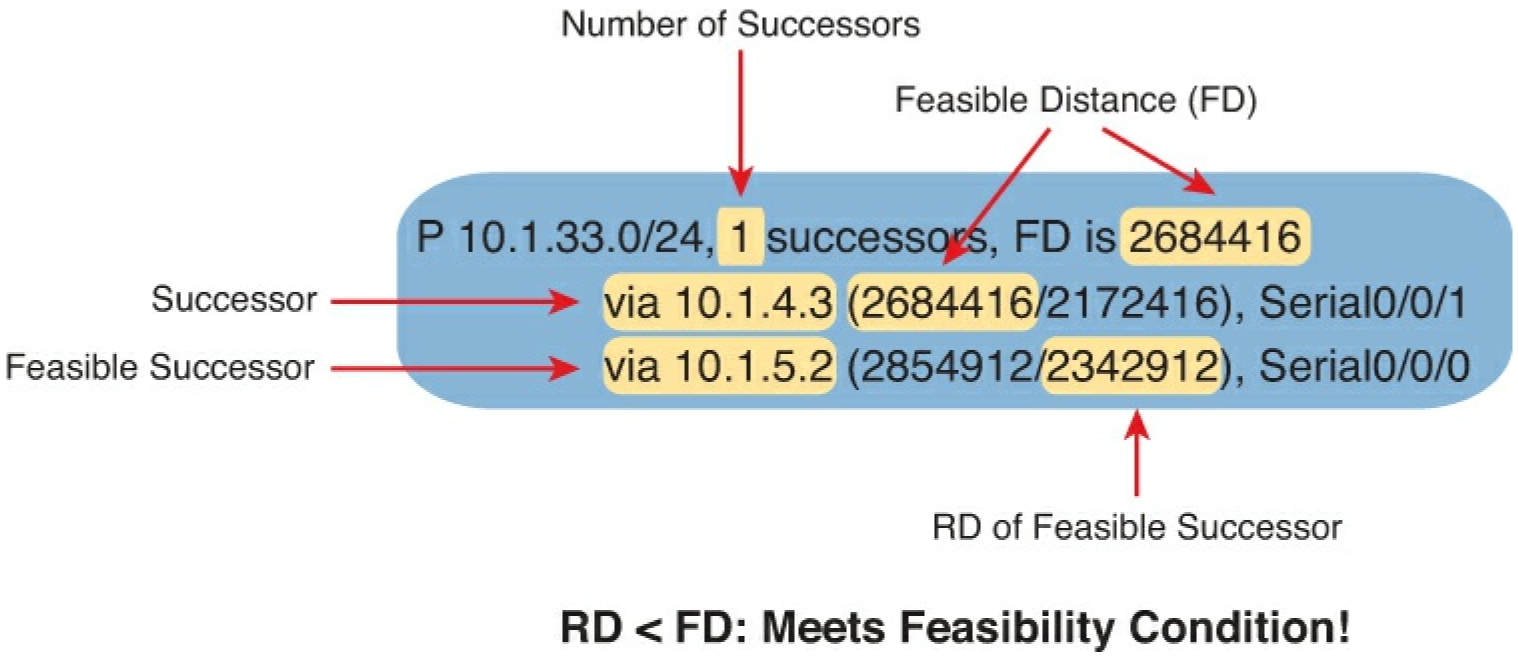

Number of Successors
Feasible Distance (FD)
P 10.1.33.0/24, 1 successors, FD is 2684416
Successor
via 10.1.4.3 (2684416/2172416), Serial0/0/1
Feasible Successor
via 10.1.5.2 (2854912/2342912), Serial0/0/0
RD of Feasible Successor
RD < FD: Meets Feasibility Condition!

Figure 10-7. Identifying the Feasible Successor Route

> **Note**
>
> The **show ip eigrp topology** command lists only successor and FS routes. To see other routes, use the **show ip eigrp topology all-links** command, which lists all routes, even those that are neither successor nor feasible successor routes.

Convergence Using the Feasible Successor Route

One motivation for EIGRP to have a FS concept is to help EIGRP converge very quickly, using a FS route immediately when a successor route fails. The next example shows the convergence process, with R1 losing its current successor route to 10.1.33.0/24, through R3, and replacing it with the FS route through R2, as shown in Figure 10-8.

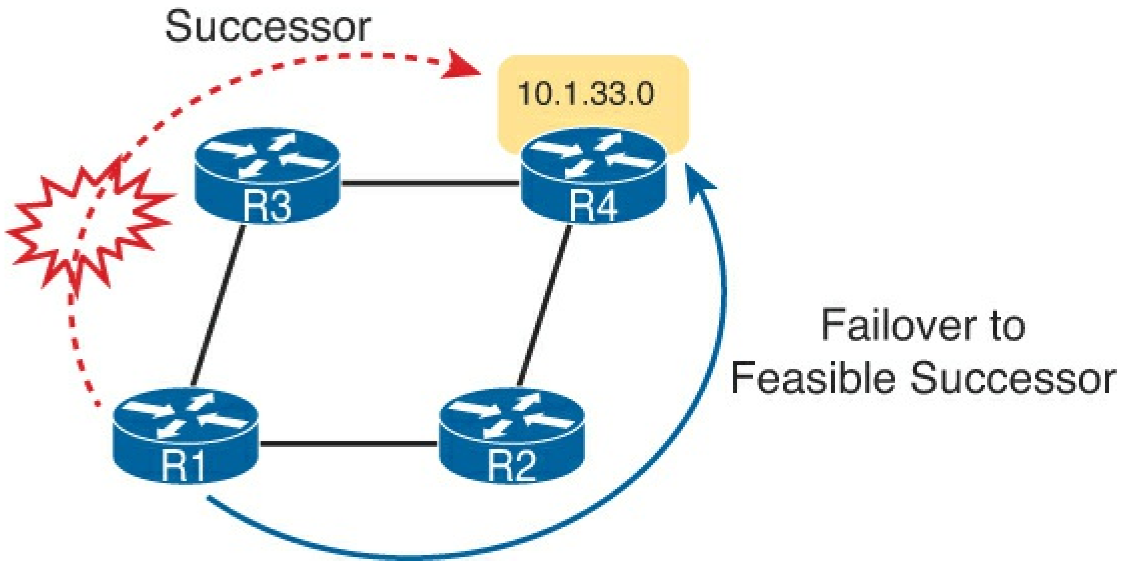


Figure 10-8. Diagram of the Convergence Event Described in the Next Example

Example 10-12 shows not only the net results of the failover and convergence, but also the process by using some **debug** messages. Be warned, some of the **debug** messages might not make a lot of sense. However, the example removes some of the less-useful messages, and highlights the more understandable output, to demonstrate what happens with the failover.

For this example, the link between R3 and R4 is disabled (**shutdown**). The **debug** messages on R1 show the effects of EIGRP's logic in changing routes. Pay particular attention to the timestamps on the debug messages, which amazingly all occur within the same millisecond.

Example 10-12. Debug Messages During Convergence to the FS Route for Subnet 10.1.33.0/24

Click here to view code image

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
! Below, debug eigrp fsm is enabled, and then R3's S0/1/0 link to R4 is disabled,
! but not shown in the example text. SOME DEBUG MESSAGES are omitted to
! improve readability.
R1# debug eigrp fsm
EIGRP FSM Events/Actions debugging is on
R1#
*Nov 13 23:50:41.099: EIGRP-IPv4(1): Find FS for dest 10.1.33.0/24. FD is 2684416, RD is 2684416 on tid 0
*Nov 13 23:50:41.099: EIGRP-IPv4(1): 10.1.4.3 metric 72057594037927935/72057594037927936
*Nov 13 23:50:41.099: EIGRP-IPv4(1): 10.1.5.2 metric 2854912/2342912 found Dmin is 2854912
*Nov 13 23:50:41.099: DUAL: AS(1) RT installed 10.1.33.0/24 via 10.1.5.2
!
! Next, R1 lists a new successor route, to 10.1.5.2: R2.
R1# show ip eigrp topology | section 10.1.33.0
P 10.1.33.0/24, 1 successors, FD is 2854912
via 10.1.5.2 (2854912/2342912), Serial0/0/0
R1# show ip route | section 10.1.33.0
D 10.1.33.0/24 [90/2854912] via 10.1.5.2, 00:16:50, Serial0/0/0
```

Finally, make sure to note the ending state of the convergence, as shown at the end of the example. The example shows R1's updated topology database entries for subnet 10.1.33.0/24, with a new successor, new FD (2,854,912 versus the old 2,684,416 shown in Example 10-10), and a new next-hop router (R2, 10.1.5.2). The last command lists the new IPv4 route, with the new FD listed as the metric in brackets, and R2 (10.1.5.2) as the new next-hop router.

Examining the Metric Components

Most of the discussion about metrics in this chapter so far has centered on the composite EIGRP metric. However, EIGRP advertises different metric components, and then uses some of those components to calculate the composite metric. Before leaving this discussion about choosing successor routes (with the best metric), and FS routes (loop-free backup routes), all based on their composite metrics, this short topic shows how to look at the individual metric components stored by EIGRP.

When using the defaults (which Cisco recommends), EIGRP bases its composite metric on the minimum bandwidth link in a route and the total delay for all links in the route. However, the EIGRP routers still advertise all the metric components, which includes the link reliability and load. Example 10-13 lists the output from the **show ip eigrp topology 10.1.3.0/24** command on router R1, a command that lists the details of the EIGRP topology data for the routes for this subnet. The highlighted lines in the example list the composite metric as well as the individual components of the metric.

Example 10-13. EIGRP Metric Components as Shown in the EIGRP Topology Database

Click here to view code image

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
R1# show ip eigrp topology 10.1.3.0/24
EIGRP-IPv4 Topology Entry for AS(1)/ID(10.1.13.1) for 10.1.3.0/24
State is Passive, Query origin flag is 1, 1 Successor(s), FD is 2172416
Descriptor Blocks:
10.1.4.3 (Serial0/0/1), from 10.1.4.3, Send flag is 0x0
Composite metric is (2172416/28160), route is Internal
Vector metric:
Minimum bandwidth is 1544 Kbit
Total delay is 20100 microseconds
Reliability is 255/255
Load is 1/255
Minimum MTU is 1500
Hop count is 1
Originating router is 3.3.3.3
10.1.5.2 (Serial0/0/0), from 10.1.5.2, Send flag is 0x0
Composite metric is (2684416/2172416), route is Internal
Vector metric:
Minimum bandwidth is 1544 Kbit
Total delay is 40100 microseconds
Reliability is 255/255
Load is 1/255
Minimum MTU is 1500
Hop count is 2
```

Other EIGRP Configuration Settings

So far, this chapter has focused on the core functions of EIGRP. The configuration details have been relatively sparse, just due to the nature of EIGRP. However, this chapter has spent a fair amount of time and effort to show the results of enabling EIGRP on the routers in a network, showing EIGRP working on interfaces, creating neighbor relationships, learning topology information, and ultimately adding routes to the IP routing table.

This third and final major section this chapter turns away from these core features. The topics in this section are either completely optional or have default settings that the chapter has not discussed so far. This section now examines this small set of other EIGRP topics, including load balancing, EIGRP metric tuning, and autosummary.

Load Balancing Across Multiple EIGRP Routes

Like OSPF, EIGRP supports the ability to put multiple equal-metric routes in the IPv4 routing table. Like OSPF, EIGRP defaults to support four such routes for each subnet, and it can be configured to other values using the **maximum-paths** *number* EIGRP subcommand. (Note that the maximum number of equal cost paths depends on the IOS version and router platform.)

In fact, Example 10-9, earlier in this chapter, showed just such an example, with router R1's route for subnet 10.1.33.0/24. Example 10-14 revisits that same scenario, this time with both the topology table and the IP routing table displayed. Due to the default EIGRP configuration setting of **maximum-paths 4**, R1 places both successor routes into R1's IP routing table.

Example 10-14. R1's Routing Table with Multiple Equal-Cost EIGRP Routes

Click here to view code image

```
R1# show ip eigrp topology | section 10.1.33.0
P 10.1.33.0/24, 2 successors, FD is 2684416
via 10.1.4.3 (2684416/2172416), Serial0/0/1
via 10.1.5.2 (2684416/2172416), Serial0/0/0

R1# show ip route | section 10.1.33.0
D 10.1.33.0/24 [90/2684416] via 10.1.5.2, 00:02:23, Serial0/0/0
[90/2684416] via 10.1.4.3, 00:02:23, Serial0/0/1
```

Although the ability to add multiple routes with exactly equal metrics may be useful, EIGRP often calculates similar metric values that do not happen to be exactly equal. EIGRP metrics often range into the millions, making it less likely that metrics would be exactly the same.

IOS also includes the concept *unequal-cost load balancing* using an EIGRP setting called *variance*, to overcome this problem. Variance allows routes whose metrics are relatively close in value to be considered equal, allowing multiple unequal-metric routes to the same subnet to be added to the routing table.

The **variance** *multiplier* EIGRP router subcommand defines an integer between 1 and 128. The router then multiplies the variance times a route's FD—the best metric with which to reach that subnet. Any FS routes whose metric is less than the product of the variance times the FD are considered to be equal routes and may be placed in the routing table, depending on the setting of the **maximum-paths** command.

The previous paragraph does summarize the rules for variance and unequal-cost load balancing, but working through the idea with an example works much better. To keep the numbers more obvious, Table 10-2 lists an example with small metric values. The table lists the metric for three routes to the same subnet, as calculated on router R4. The table also lists the neighboring routers' RD and the decision to add routes to the routing table based on various variance settings.

Table 10-2. Example of Routes Chosen as Equal Because of Variance

Next Hop	Metric	RD	Added to RT at Variance 1?	Added to RT at Variance 2?	Added to RT at Variance 3?
R1	50	30	Yes	Yes	Yes
R2	90	40	No	Yes	Yes
R3	120	60	No	No	No

Before considering the variance, note that in this case the route through R1 is the successor route because it has the lowest metric. This also means that the metric for the route through R1, 50, is the FD. The route through R2 is an FS route because its RD of 40 is less than the FD of 50. The route through R3 is not an FS route because its RD of 60 is more than the FD of 50.

At a default configuration of **variance 1**, the metrics must be exactly equal to be considered equal, so only the successor route is added to the routing table.

With the **variance 2** command configured, the FD (50) is multiplied by the variance (2) for a product of 100. The route through R2, with metric 90, is less than the calculated variance × FD = 100, so R4 adds the route through R2 to the routing table as well. The router can then load balance traffic across these two routes. The third route's metric, 120, is more than the calculated variance × FD = 100, so it is not added to the routing table.

With the **variance 3** command configured, the product of the FD (50) times 3 results in a product of 150, and all three routes' calculated metrics are less than 150. However, the route through R3 is not an FS route, so it cannot be added to the routing table for fear of causing a routing loop.

The following list summarizes the key points about variance:

Key Topic

- The variance is multiplied by the current FD (the metric of the best route to reach the subnet).
- Any FS routes whose calculated metric is less than or equal to the product of variance times the FD are added to the IP routing table, assuming that the **maximum-paths** setting allows more routes.
- Routes that are neither successor nor FS can never be added to the IP routing table, regardless of the variance setting, because doing so may cause packets to loop.

As soon as the routes have been added to the routing table, the router supports a variety of options for how to load balance traffic across the routes. The router can balance the traffic proportionally with the metrics, meaning that lower metric routes send more packets. The router can send all traffic over the lowest-metric route, with the other routes just being in the routing table for faster convergence in case the best route fails. However, the details of the load-balancing process require a much deeper discussion of the internals of the forwarding process in IOS, and this topic is beyond the scope of this book.

Tuning the EIGRP Metric Calculation

By default, EIGRP calculates an integer metric based on interface bandwidth and delay. You can change the settings on any interface using the **bandwidth** *value* and the **delay** *value* interface subcommands, which in turn influences a router's choice of routes.

Cisco recommends setting each interface's bandwidth to an accurate value, rather than setting the bandwidth to some inaccurate value for the purpose of changing EIGRP's metric calculation. Router serial links should be configured with the **bandwidth** *speed* command, with a speed value in kilobits per second (Kbps), matching the interface's actual speed. Router Ethernet interfaces can use default settings; by default, IOS actually changes the router Ethernet interface bandwidth setting to match the actual physical transmission speed.

Because fewer other IOS features rely on the interface delay setting, Cisco recommends that if you want to tune EIGRP metric, change the interface delay settings. To change an interface's delay setting, use the **delay** *value* command, where the *value* is a delay setting with an unusual unit: tens of microseconds. Interestingly, the EIGRP metric formula also uses the unit of tens of microseconds; however, **show** commands list the delay with a unit of microseconds, as shown in Example 10-15 with the following details:

1. The router's Fa0/0 has a default delay setting of 100 microseconds (usec), assuming the interface is actually running at a speed of 100 Mbps.
2. The **delay 123** command is configured on the interface, meaning 123 tens of microseconds.
3. The **show interfaces fa0/0** command now lists a delay of 1230 microseconds.

Example 10-15. Configuring Interface Delay

Click here to view code image

```
Yosemite# show interfaces fa0/0
FastEthernet0/0 is up, line protocol is up
Hardware is Gt96k FE, address is 0013.197b.5026 (bia 0013.197b.5026)
Internet address is 10.1.2.252/24
MTU 1500 bytes, BW 100000 Kbit, DLY 100 usec,
! lines omitted for brevity

Yosemite# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
Yosemite(config)# interface fa0/0
Yosemite(config-if)# delay 123
Yosemite(config-if)# ^Z

Yosemite# show interfaces fa0/0
FastEthernet0/0 is up, line protocol is up
Hardware is Gt96k FE, address is 0013.197b.5026 (bia 0013.197b.5026)
Internet address is 10.1.2.252/24
MTU 1500 bytes, BW 100000 Kbit, DLY 1230 usec,
! lines omitted for brevity
```

Autosummarization and Discontiguous Classful Networks

Older routing protocols, namely RIP-1 and IGRP, were classified as *classful routing protocols*. This term comes from the fact that these classful routing protocols had to pay more attention to details about Class A, B, and C networks, in part because of the simplicity of the routing protocol.

These older classful routing protocols also had to use a more careful and cautious subnet design plan to avoid a problem called a discontiguous classful network. These simpler old routing protocols just got confused when a classful network became discontiguous, because of a required feature of classful routing protocols called autosummarization.

Today, most enterprises use OSPF or EIGRP, or in rare cases, RIP-2. All these protocols are classless routing protocols. As a result, these newer routing protocols can be configured so that the old problem with discontiguous classful networks is not a problem at all.

However, while the more recent IOS versions use good default settings so that this problem can be ignored, EIGRP allows the possibility of enabling the autosummary feature, which then requires the network engineer to be aware of this old discontiguous network problem. So, just in case, these next few pages first discuss the autosummary feature, followed by a discussion of the routing problems that can occur as a result.

Note

In real networks, most people simply choose to avoid using autosummary today.

Automatic Summarization at the Boundary of a Classful Network

A routing protocol that uses autosummary automatically creates a summary route under certain conditions. In particular, when a router sits at the boundary between classful networks—that is, with some interfaces in one Class A, B, or C network and other interfaces in another Class A, B, or C network—the router summarizes routes. Routes from one classful network are summarized as one route to the entire Class A, B, or C network. More formally:

Key Topic

> Routes related to subnets in network X, when advertised out an interface whose IP address is not in network X, are summarized and advertised as one route. That route is for the entire Class A, B, or C network X.

As usual, an example makes the concept much clearer. Consider Figure 10-9, which shows two networks in use: 10.0.0.0 and 172.16.0.0. R3 has four (connected) routes to subnets of network 10.0.0.0 on the right, and one interface on the left connected to a different classful network, class B network 172.16.0.0. As a result, R3, with autosummary enabled, will summarize a route for all of class A network 10.0.0.0.

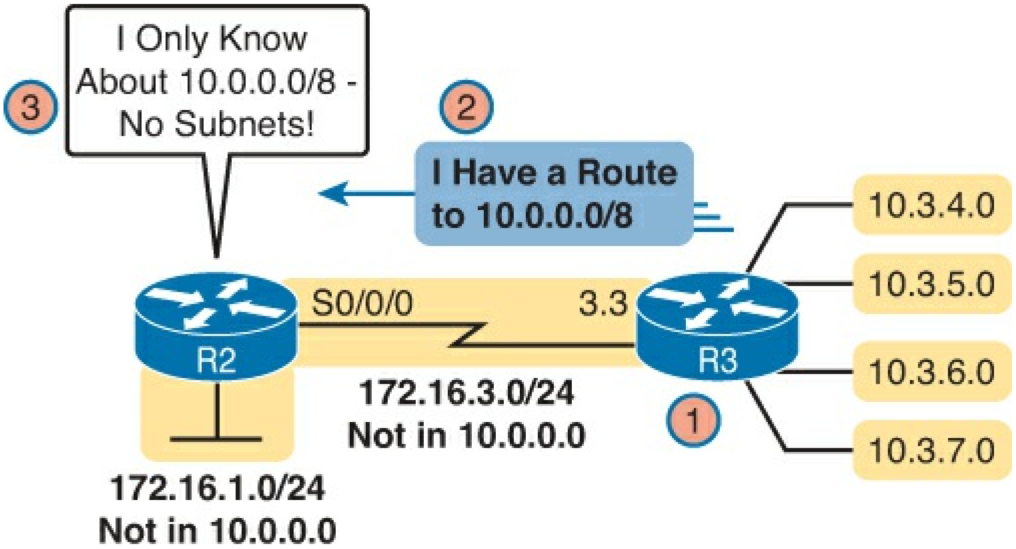

③
I Only Know About 10.0.0.0/8 - No Subnets!
②
I Have a Route to 10.0.0.0/8
10.3.4.0
10.3.5.0
S0/0/0
3.3
R2
R3
10.3.6.0
172.16.3.0/24 Not in 10.0.0.0
①
10.3.7.0
172.16.1.0/24 Not in 10.0.0.0

Figure 10-9. Autosummarization

Let's follow the steps in the figure:

1. R3 has autosummary enabled, with the EIGRP **autosummary** router subcommand.
2. R3 advertises a route for all of Class A network 10.0.0.0, instead of advertising routes for each subnet inside network 10.0.0.0 because the link to R2 is a link in another network (172.16.0.0).
3. R2 learns one route in network 10.0.0.0: A route to 10.0.0.0/8, which represents all of network 10.0.0.0, with R3 as the next-hop router.

Example 10-16 shows the output of the **show ip route** command on R2, confirming the effect of the **autosummary** setting on R3.

Example 10-16. R2 with a Single Route in Network 10.0.0.0 for the Entire Network

Click here to view code image

```
R2# show ip route eigrp
! lines omitted for brevity

D 10.0.0.0/8 [90/2297856] via 172.16.3.3, 00:12:59, Serial0/0/0
```

Note that **autosummary** by itself causes no problems. In the design shown in Figure 10-9, and in the command output in Example 10-16, no problems exist. R2 can forward packets to all subnets of network 10.0.0.0 using the one highlighted summary route, sending those packets to R3 next.

Discontiguous Classful Networks

Autosummarization does not cause any problems as long as the summarized network is contiguous rather than discontiguous. U.S. residents can appreciate the concept of a discontiguous network based on the common term *contiguous 48*, referring to the 48 U.S. states besides Alaska and Hawaii. To drive to Alaska from the contiguous 48, for example, you must drive through another country (Canada, for the geographically impaired), so Alaska is not contiguous with the 48 states. In other words, it is discontiguous.

To better understand what the terms *contiguous* and *discontiguous* mean in networking, refer to the following two formal definitions when reviewing the example of a discontiguous classful network that follows:

Key Topic

- **Contiguous network**: A classful network in which packets sent between every pair of subnets can pass only through subnets of that same classful network, without having to pass through subnets of any other classful network
- **Discontiguous network**: A classful network in which packets sent between at least one pair of subnets must pass through subnets of a different classful network

Figure 10-10 creates an expanded version of the internetwork shown in Figure 10-9 to create an example of a discontiguous network 10.0.0.0. In this design, some subnets of network 10.0.0.0 sit off R1 on the left, whereas others still connect to R3 on the right. Packets passing between subnets on the left to subnets on the right must pass through subnets of Class B network 172.16.0.0.

Key Topic

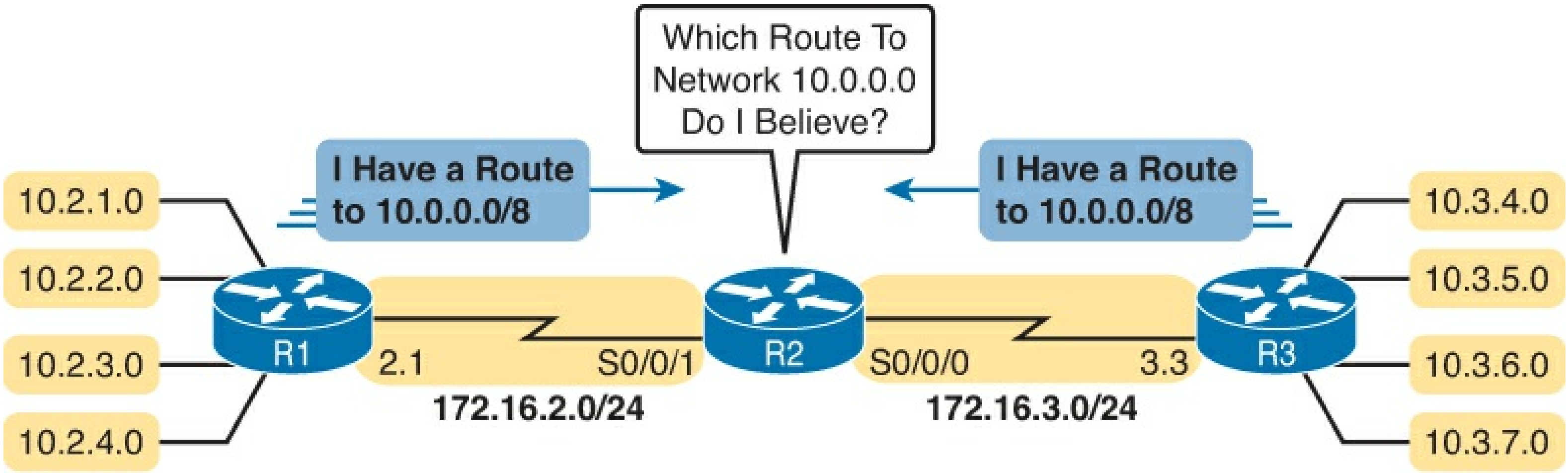


Figure 10-10. Discontiguous Network 10.0.0.0

Autosummarization causes problems in that routers like R2 that sit totally outside the discontiguous network become totally confused about how to route packets to the discontiguous network. Figure 10-10 shows the idea, with both R1 and R3 advertising a route for 10.0.0.0/8 to R2 in the middle of the network. Example 10-17 shows the resulting routes on router R2.

Example 10-17. Albuquerque Routing Table: Autosummarization Causes Routing Problem with Discontiguous Network 10.0.0.0

Click here to view code image

```
R2# show ip route | section 10.0.0.0
D 10.0.0.0/8 [90/2297856] via 172.16.3.3, 00:00:15, Serial0/0/0
[90/2297856] via 172.16.2.1, 00:00:15, Serial0/0/1
```

As shown in Example 10-17, R2 now has two routes to network 10.0.0.0/8: one pointing left toward R1 and one pointing right toward R3. R2 simply uses its usual load-balancing logic, because as far as R2 can tell, the two routes are simply equal-cost routes to the same destination: the entire network 10.0.0.0. Sometimes R2 happens to forward a packet toward the correct destination, and sometimes not.

This problem has two solutions. The old-fashioned solution is to create IP addressing plans that do not create discontiguous classful networks. The other: Just do not use autosummary, by using EIGRP defaults, or by disabling it with the **no autosummary** EIGRP subcommand. Example 10-18 shows the resulting routing table in R2 for routes in network 10.0.0.0 with the **no autosummary** command configured on routers R1 and R3.

Example 10-18. Classless Routing Protocol with No Autosummarization Allows Discontiguous Network

Click here to view code image

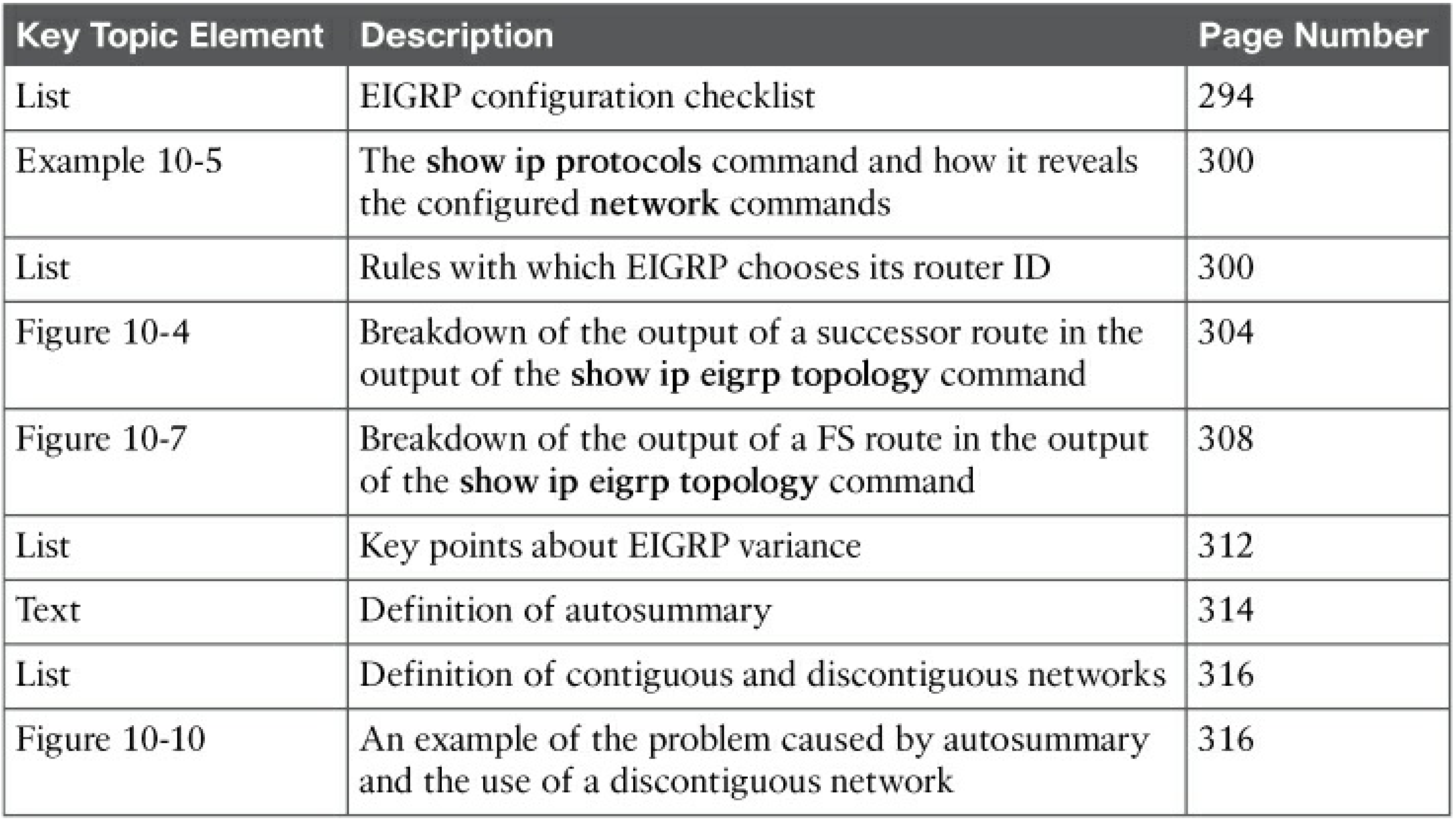
```
R2# show ip route 10.0.0.0
Routing entry for 10.0.0.0/24, 8 known subnets
Redistributing via eigrp 1
D 10.2.1.0 [90/2297856] via 172.16.2.1, 00:00:12, Serial0/0/1
D 10.2.2.0 [90/2297856] via 172.16.2.1, 00:00:12, Serial0/0/1
D 10.2.3.0 [90/2297856] via 172.16.2.1, 00:00:12, Serial0/0/1
D 10.2.4.0 [90/2297856] via 172.16.2.1, 00:00:12, Serial0/0/1
D 10.3.4.0 [90/2297856] via 172.16.3.3, 00:00:06, Serial0/0/0
D 10.3.5.0 [90/2297856] via 172.16.3.3, 00:00:06, Serial0/0/0
D 10.3.6.0 [90/2297856] via 172.16.3.3, 00:00:06, Serial0/0/0
D 10.3.7.0 [90/2297856] via 172.16.3.3, 00:00:06, Serial0/0/0
```

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 10-3 lists these key topics and where each is discussed.

Table 10-3. Key Topics for Chapter 10



Key Topic Element	Description	Page Number
List	EIGRP configuration checklist	294
Example 10-5	The **show ip protocols** command and how it reveals the configured **network** commands	300
List	Rules with which EIGRP chooses its router ID	300
Figure 10-4	Breakdown of the output of a successor route in the output of the **show ip eigrp topology** command	304
Figure 10-7	Breakdown of the output of a FS route in the output of the **show ip eigrp topology** command	308
List	Key points about EIGRP variance	312
Text	Definition of autosummary	314
List	Definition of contiguous and discontiguous networks	316
Figure 10-10	An example of the problem caused by autosummary and the use of a discontiguous network	316

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix D, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix E, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Definitions of Key Terms

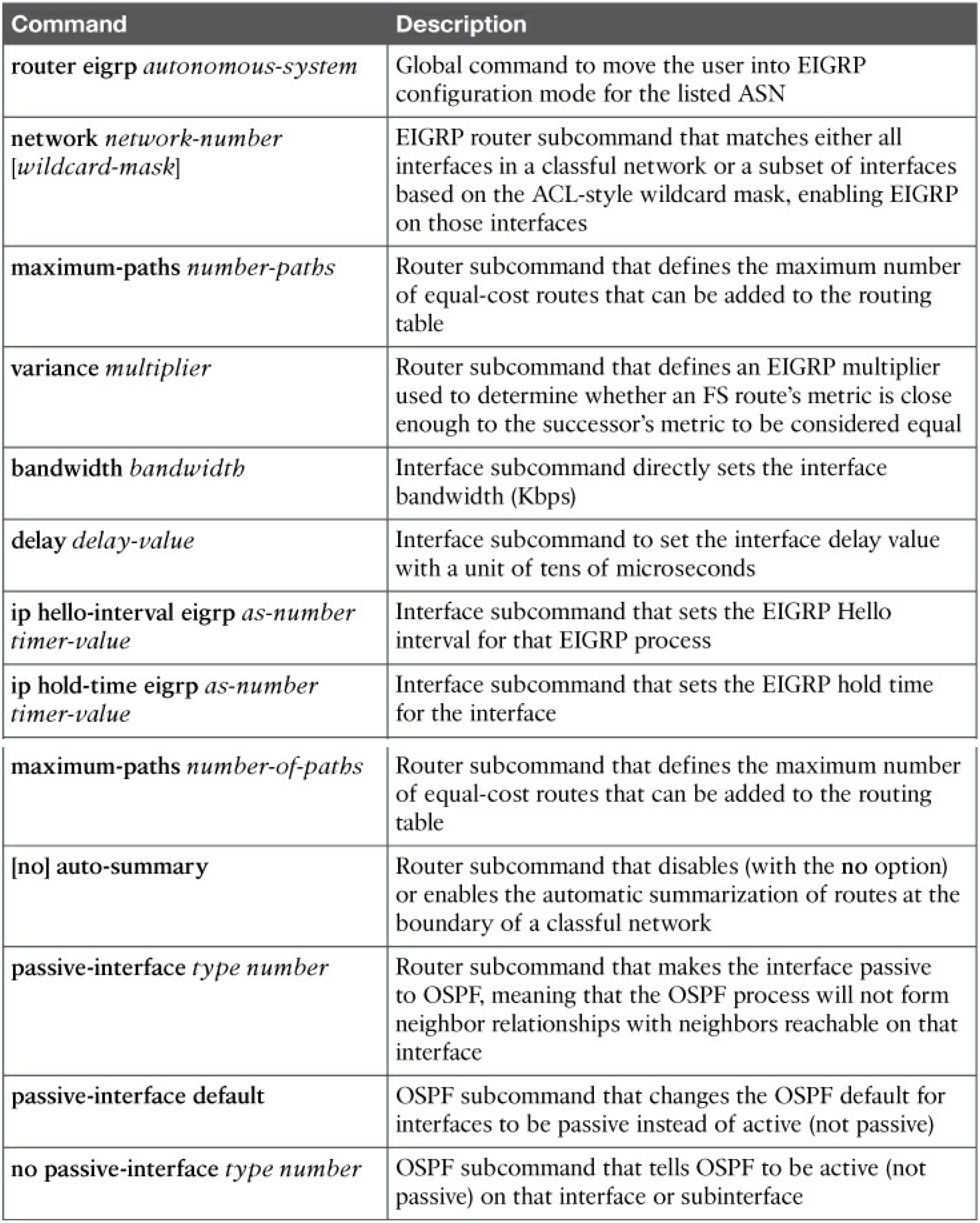
After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22 directs you in how to use these terms for late-stage preparation for the exam.

feasibility condition
feasible distance
feasible successor
reported distance
successor
unequal cost load balancing
variance
autosummary
discontiguous network

Command Reference to Check Your Memory

Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table, read the descriptions on the right side, and see if you remember the command.

Table 10-4. Chapter 10 Configuration Command Reference



Command	Description
router eigrp *autonomous-system*	Global command to move the user into EIGRP configuration mode for the listed ASN
network *network-number* [*wildcard-mask*]	EIGRP router subcommand that matches either all interfaces in a classful network or a subset of interfaces based on the ACL-style wildcard mask, enabling EIGRP on those interfaces
maximum-paths *number-paths*	Router subcommand that defines the maximum number of equal-cost routes that can be added to the routing table
variance *multiplier*	Router subcommand that defines an EIGRP multiplier used to determine whether an FS route's metric is close enough to the successor's metric to be considered equal
bandwidth *bandwidth*	Interface subcommand directly sets the interface bandwidth (Kbps)
delay *delay-value*	Interface subcommand to set the interface delay value with a unit of tens of microseconds
ip hello-interval eigrp *as-number timer-value*	Interface subcommand that sets the EIGRP Hello interval for that EIGRP process
ip hold-time eigrp *as-number timer-value*	Interface subcommand that sets the EIGRP hold time for the interface
maximum-paths *number-of-paths*	Router subcommand that defines the maximum number of equal-cost routes that can be added to the routing table
[no] auto-summary	Router subcommand that disables (with the **no** option) or enables the automatic summarization of routes at the boundary of a classful network
passive-interface *type number*	Router subcommand that makes the interface passive to OSPF, meaning that the OSPF process will not form neighbor relationships with neighbors reachable on that interface
passive-interface default	OSPF subcommand that changes the OSPF default for interfaces to be passive instead of active (not passive)
no passive-interface *type number*	OSPF subcommand that tells OSPF to be active (not passive) on that interface or subinterface

Table 10-5. Chapter 10 EXEC Command Reference

Command	Description
show ip eigrp interfaces	Lists one line per interface on which EIGRP has been enabled, but for which it is not made passive with the **passive-interface** configuration command
show ip eigrp interfaces *type number*	Lists statistics interfaces on which EIGRP has been enabled, but for which it is not made passive with the **passive-interface** configuration command
show ip eigrp interfaces detail [*type number*]	Lists detailed configuration and statistics, for all interfaces or for the listed interface, again for enabled interfaces that are not passive
show ip protocols	Shows routing protocol parameters and current timer values
show ip eigrp neighbors	Lists EIGRP neighbors and status
show ip eigrp neighbors *type number*	Lists EIGRP neighbors reachable off the listed interface
show ip eigrp topology	Lists the contents of the EIGRP topology table, including successors and FSs
show ip eigrp topology *subnet/prefix*	Lists detailed topology information about the listed subnet
show ip eigrp topology | section *subnet*	Lists a subset of the **show ip eigrp topology** command (just the section for the listed subnet ID)
show ip route	Lists all IPv4 routes
show ip route eigrp	Lists routes in the IPv4 routing table learned by EIGRP
show ip route *ip-address mask*	Shows a detailed description of the route for the listed subnet/mask
show ip route | section *subnet*	Lists a subset of the **show ip route** command: just the section for the listed subnet ID
debug eigrp fsm	Displays changes to the EIGRP successor and FS routes

Chapter 11. Troubleshooting IPv4 Routing Protocols

This chapter covers the following exam topics:

Troubleshooting

- Troubleshoot and Resolve OSPF problems
  - Neighbor adjacencies
  - Hello and Dead timers
  - OSPF area
  - Interface MTU
  - Network types
  - Neighbor states
  - OSPF topology database
- Troubleshoot and Resolve EIGRP problems
  - Neighbor adjacencies
  - AS number
  - Load balancing
  - Split horizon

To begin the problem-isolation process when troubleshooting a possible IPv4 routing protocol problem, first focus on interfaces, and then on neighbors. The routing protocol configuration identifies the interfaces on which the router should use the routing protocol. After identifying those interfaces, a network engineer can look at the neighbors each router finds on each interface, searching for neighbors that should exist but do not.

This chapter focuses on issues related to these two main branches of logic: on which interfaces should a router enable the routing protocol and which neighbor relationships should each router create. This chapter relies on the configuration discussed in the other three chapters in this part of the book (Chapters 8, "Implementing OSPF for IPv4," 9, "Understanding EIGRP Concepts," and 10, "Implementing EIGRP for IPv4"), while emphasizing how to find incorrect configuration problems by using only **show** and **debug** commands.

This chapter first briefly introduces a few broad concepts related to troubleshooting problems with routing protocols. The next major section examines problems related to which interfaces on which a router enables the routing protocol, with the final major section focusing of routing protocol neighbor relationships. Note that the entire chapter moves back and forth between discussing both Enhanced Interior Gateway Routing Protocol (EIGRP) and Open Shortest Path First (OSPF).

"Do I Know This Already?" Quiz

The troubleshooting chapters of this book pull in concepts from many other chapters, including some chapters in *Cisco CCENT/CCNA ICND1 Official Cert Guide*. They also show you how to approach some of the more challenging questions on the CCNA exams. Therefore, it is useful to read these chapters regardless of your current knowledge level. For these reasons, the troubleshooting chapters do not include a "Do I Know This Already?" quiz. However, if you feel particularly confident about troubleshooting OSPF and EIGRP, feel free to move to the "Exam Preparation Tasks" section near the end of this chapter to bypass the majority of the chapter.

Foundation Topics

Perspectives on Troubleshooting Routing Protocol Problems

Because a routing protocol's job is to fill a router's routing table with the currently best routes, it makes sense that troubleshooting potential problems with routing protocols could begin with the IP routing table. Given basic information about an internetwork, including the routers, their IP addresses and masks, and the routing protocol, you could calculate the subnet numbers that should be in the router's routing table and list the likely next-hop routers for each route. For example, Figure 11-1 shows an internetwork with six subnets. Router R1's routing table should list all six subnets, with three connected routes, two routes learned from R2 (172.16.4.0/24 and 172.16.5.0/24), and one route learned from R3 (172.16.6.0/24).

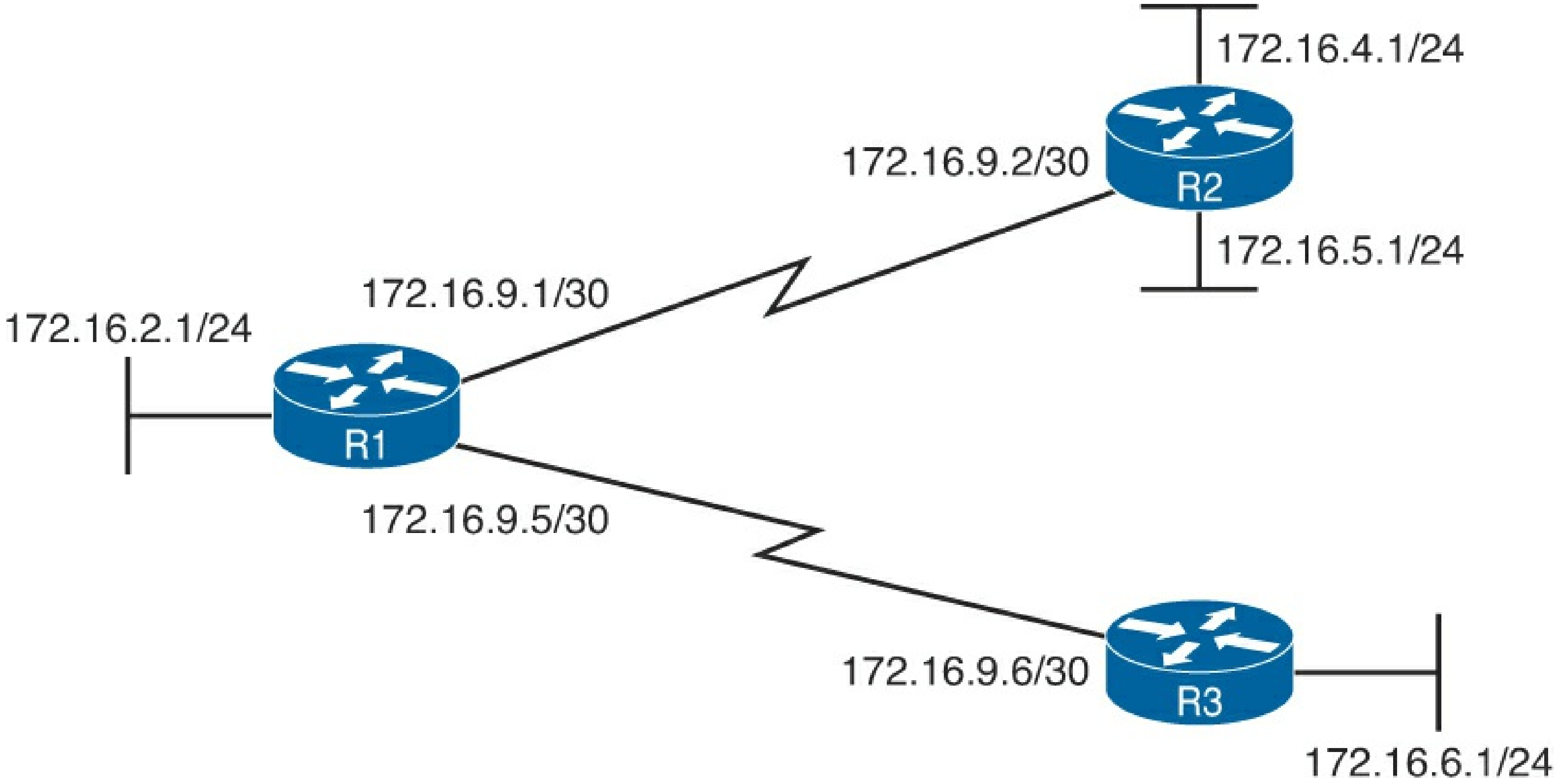


Figure 11-1. Internetwork with Six Subnets

So, one possible troubleshooting process is to analyze the internetwork, look at the routing table, and look for missing routes. If one or more expected routes are missing, the next step would be to determine whether that router has learned any routes from the expected next-hop (neighbor) router. The next steps to isolate the problem differ greatly if a router is having problems forming a neighbor relationship with another router, versus having a working neighbor relationship but not being able to learn all routes.

For example, suppose that R1 in Figure 11-1 has learned a route for subnet 172.16.4.0/24 in Figure 11-1 but not for subnet 172.16.5.0/24. In this case, it is clear that R1 has a working neighbor relationship with R2. In these cases, the root cause of this problem might still be related to the routing protocol, or it might be unrelated to the routing protocol. For example, the problem may be that R2's lower LAN interface is down. However, if R1 did not have a route for either 172.16.4.0/24 or 172.16.5.0/24, R1's neighbor relationship with R2 could be the problem.

Troubleshooting routing protocol problems in real internetworks can be very complex—much more complex than even the most difficult CCNA exam questions. Defining a generic troubleshooting process with which to attack both simple and complex routing protocol problems would require a lot of space and be counterproductive for preparing for the CCNA exams. This chapter instead offers a straightforward process for attacking routing protocol problems—specifically, problems similar to the depth and complexity of the CCNA exams.

If an exam question appears to be related to a problem with a routing protocol, you can quickly identify some common configuration errors with the following process—even if the question does not list the configuration. The process has three main tasks:

Step 1. Examine the internetwork design to determine on which interfaces the routing protocol should be enabled and which routers are expected to become neighbors.

Step 2. Verify whether the routing protocol is enabled on each interface (as per Step 1). If it isn't, determine the root cause and fix the problem.

Step 3. Verify that each router has formed all expected neighbor relationships. If it hasn't, find the root cause and fix the problem.

For instance, as noted with asterisks in Figure 11-2, each router should enable the routing protocol on each of the interfaces shown in the figure. Also, routing protocol neighbor relationships should form between R1 and R2, and R1 and R3, but not between R2 and R3.

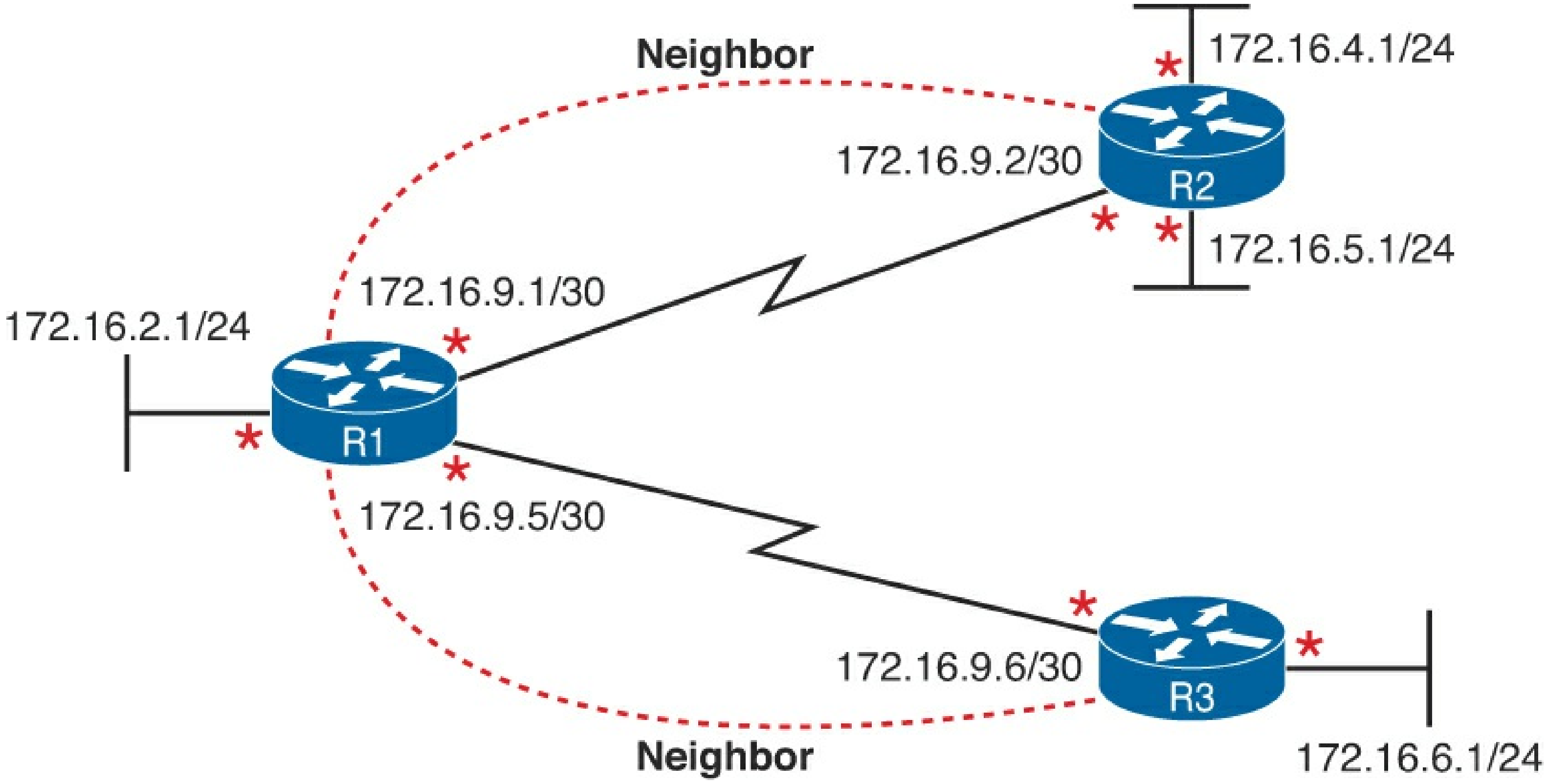


Figure 11-2. Routing Protocol Interfaces and Neighbor Relationships

While the concepts outlined in Figure 11-2 should be somewhat obvious by now, this chapter discusses how some of the most common configuration mistakes can impact the interfaces used by a routing protocol and whether a routing protocol creates neighbor relationships.

Interfaces Enabled with a Routing Protocol

This section examines the second major troubleshooting step outlined in the previous section of the chapter: how to verify the interfaces on which the routing protocol has been enabled. Both EIGRP and OSPF configuration enable the routing protocol on an interface by using the **network** router subcommand. For any interfaces matched by the **network** commands, the routing protocol tries the following two actions:

- Attempt to find potential neighbors on the subnet connected to the interface
- Advertise the subnet connected to that interface

At the same time, the **passive-interface** router subcommand can be configured so that the router does not attempt to find neighbors on the interface (the first action just listed), but still advertises the connected subnet (the second action).

Three **show** commands are all that is needed to know exactly which interfaces have been enabled with EIGRP and which interfaces are passive. In particular, the **show ip eigrp interfaces** command lists all EIGRP-enabled interfaces that are not passive interfaces. The **show ip protocols** command essentially lists the contents of the configured **network** commands for each routing protocol and a separate list of the passive interfaces. Comparing these two commands identifies all EIGRP-enabled interfaces and those that are passive.

For OSPF, the command works slightly differently, with the **show ip ospf interface brief** command listing all OSPF-enabled interfaces (including passive interfaces). Using this command, along with the list of passive interfaces listed by the **show ip protocols** command, again identifies all fully enabled OSPF interfaces as well as all passive interfaces.

Table 11-1 summarizes these commands for easier reference.

Table 11-1. Key Commands to Find Routing Protocol-Enabled Interfaces

Command	Key Information	Lists Passive Interfaces?
show ip eigrp interfaces	Lists the interfaces on which the routing protocol is enabled (based on the **network** commands), *excluding* passive interfaces.	No
show ip ospf interface brief	Lists the interfaces on which the OSPF is enabled (based on the **network** commands), *including* passive interfaces.	Yes
show ip protocols	Lists the contents of the **network** configuration commands for each routing process, and lists enabled but passive interfaces.	Yes

Note

All the commands in Table 11-1 list the interfaces regardless of interface status, in effect telling you the results of the **network** and **passive-interface** configuration commands.

So, for the major troubleshooting step covered in this section, the task is to use the commands in Table 11-1 and analyze the output. First, an EIGRP example will be shown, followed by an OSPF example.

EIGRP Interface Troubleshooting

This section shows a few examples of the commands in the context of Figure 11-3, which is used in all the examples in this chapter.

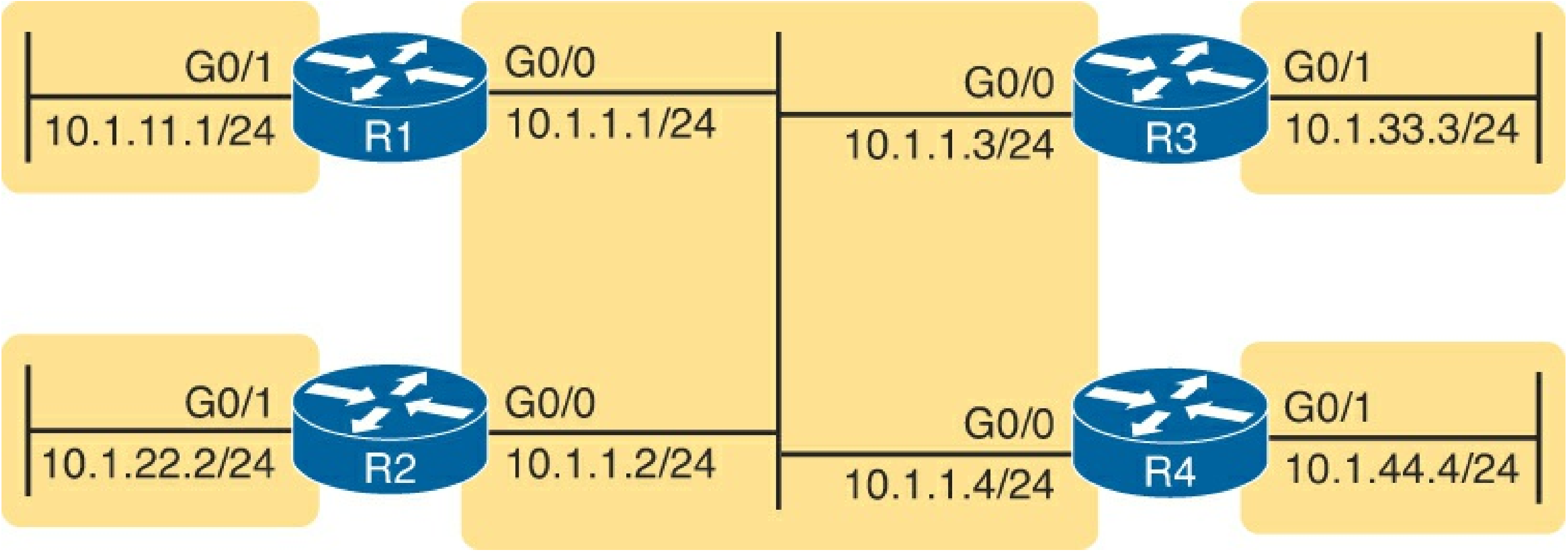


Figure 11-3. Internetwork for EIGRP/OSPF Troubleshooting Examples

This example includes four routers, with the following scenario in this case:

- R1 and R2 are configured correctly on both LAN interfaces.
- R3 is mistakenly not enabled with EIGRP on its G0/1 interface.
- R4 meant to use a **passive-interface G0/1** command because no other routers are off R4's G0/1 LAN. However, R4 has instead configured a **passive-interface G0/0** command.

This example begins by showing the working details between routers R1 and R2, and then moves on to discuss the issues related to R3 and R4.

Examining Working EIGRP Interfaces

Examples 11-1 and 11-2 list configuration and **show** commands, for R1 and R2, respectively. Each lists the related configuration, the **show ip eigrp interfaces** and **show ip protocols** command, and the EIGRP-learned routes on each router.

Example 11-1. EIGRP Interfaces Problem: R1 Commands

Click here to view code image

```
R1# show running-config
! only pertinent lines shown
router eigrp 99
network 10.0.0.0
!
R1# show ip eigrp interfaces
EIGRP-IPv4 Interfaces for AS(99)
Xmit Queue PeerQ Mean Pacing Time Multicast Pending
Interface Peers Un/Reliable Un/Reliable SRTT Un/Reliable Flow Timer Routes
Gi0/0 3 0/0 0/0 2 0/0 50 0
Gi0/1 0 0/0 0/0 0 0/0 0 0

R1# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "eigrp 99"
Outgoing update filter list for all interfaces is not set
Incoming update filter list for all interfaces is not set
Default networks flagged in outgoing updates
Default networks accepted from incoming updates
EIGRP-IPv4 Protocol for AS(99)
Metric weight K1=1, K2=0, K3=1, K4=0, K5=0
NSF-aware route hold timer is 240
Router-ID: 1.1.1.1
Topology : 0 (base)
Active Timer: 3 min
Distance: internal 90 external 170
Maximum path: 4
Maximum hopcount 100
Maximum metric variance 1

Automatic Summarization: disabled
Maximum path: 4
Routing for Networks:
10.0.0.0
Routing Information Sources:
Gateway Distance Last Update
10.1.1.2 90 09:55:51
10.1.1.3 90 00:02:00
Distance: internal 90 external 170

R1# show ip route eigrp
! Legend omitted for brevity

10.0.0.0/8 is variably subnetted, 5 subnets, 2 masks
D 10.1.22.0/24 [90/30720] via 10.1.1.2, 00:00:40, GigabitEthernet0/0
```

Example 11-2. EIGRP Interfaces Problem: R2 Commands

Click here to view code image

```
R2# show running-config
! only pertinent lines shown
router eigrp 99
network 10.1.0.0 0.0.255.255

R2# show ip eigrp interfaces
EIGRP-IPv4 Interfaces for AS(99)
Xmit Queue PeerQ Mean Pacing Time Multicast Pending
Interface Peers Un/Reliable Un/Reliable SRTT Un/Reliable Flow Timer Routes
Gi0/0 2 0/0 0/0 1 0/1 50 0
Gi0/1 0 0/0 0/0 0 0/0 0 0

R2# show ip protocols
```

```
*** IP Routing is NSF aware ***

Routing Protocol is "eigrp 99"
Outgoing update filter list for all interfaces is not set
Incoming update filter list for all interfaces is not set
Default networks flagged in outgoing updates
Default networks accepted from incoming updates
EIGRP-IPv4 Protocol for AS(99)
Metric weight K1=1, K2=0, K3=1, K4=0, K5=0
NSF-aware route hold timer is 240
Router-ID: 2.2.2.2
Topology : 0 (base)
Active Timer: 3 min
Distance: internal 90 external 170
Maximum path: 4
Maximum hopcount 100
Maximum metric variance 1

Automatic Summarization: disabled
Maximum path: 4
Routing for Networks:
10.1.0.0/16
Routing Information Sources:
Gateway Distance Last Update
10.1.1.3 90 00:02:30
10.1.1.1 90 09:56:20
Distance: internal 90 external 170

R2# show ip route eigrp
! Legend omitted for brevity
10.0.0.0/8 is variably subnetted, 5 subnets, 2 masks
D 10.1.11.0/24 [90/30720] via 10.1.1.1, 00:03:25, GigabitEthernet0/0
```

The **show ip eigrp interfaces** command output on both R1 and R2 shows how both R1 and R2 have configured EIGRP using process ID 99, and that EIGRP has been enabled on both G0/0 and G0/1 on both these routers. This command lists only interfaces on which EIGRP has been enabled, excluding passive interfaces.

The highlighted parts of the **show ip protocols** command output on each router are particularly interesting. These sections show the parameters of the configured **network** commands. The **show ip protocols** command lists a separate line under the header "Routing for Networks," one for each configured **network** command. Example 11-1's output suggests R1 has a **network 10.0.0.0** configuration command (as shown at the beginning of the example), and Example R2's "10.1.0.0/16" suggests R2 has a **network 10.1.0.0 0.0.255.255** command.

Examining the Problems with EIGRP Interfaces

The next few pages now look at the problems caused by the configuration on routers R3 and R4.

First, Example 11-2 gives brief insight into the current problem caused by R3. The end of R2's **show ip protocols** command (Example 11-2) lists two routing information sources: 10.1.1.1 (R1) and 10.1.1.3 (R3). However, R2 has learned only one EIGRP route (10.1.11.0/24), as shown in the **show ip route eigrp** command output. When working properly, R2 should learn three EIGRP routes—one for each of the other LAN subnets shown in Figure 11-3.

Example 11-3 shows the root cause on R3. First, R3's **show ip eigrp interfaces** command list G0/0, but not G0/1, so a problem might exist with how EIGRP has been configured on G0/1. The configuration at the top of the example lists the root cause: an incorrect **network** command, which does not enable EIGRP on R3's G0/1 interface.

Example 11-3. EIGRP Problems on R3

Click here to view code image

```
R3# show running-config
! lines omitted for brevity
router eigrp 99
network 10.1.1.3 0.0.0.0
network 10.1.13.3 0.0.0.0
auto-summary

R3# show ip eigrp interfaces
EIGRP-IPv4 Interfaces for AS(99)
Xmit Queue PeerQ Mean Pacing Time Multicast Pending
Interface Peers Un/Reliable Un/Reliable SRTT Un/Reliable Flow Timer Routes
```

```
Gi0/0 2 0/0 0/0 1 0/1 50 0

R3# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "eigrp 99"
Outgoing update filter list for all interfaces is not set
Incoming update filter list for all interfaces is not set
Default networks flagged in outgoing updates
Default networks accepted from incoming updates
EIGRP-IPv4 Protocol for AS(99)
Metric weight K1=1, K2=0, K3=1, K4=0, K5=0
NSF-aware route hold timer is 240
Router-ID: 3.3.3.3
Topology : 0 (base)
Active Timer: 3 min
Distance: internal 90 external 170
Maximum path: 4
Maximum hopcount 100
Maximum metric variance 1

Automatic Summarization: disabled
Maximum path: 4
Routing for Networks:
10.1.1.3/32
10.1.13.3/32
Routing Information Sources:
Gateway Distance Last Update
10.1.1.2 90 00:05:14
10.1.1.1 90 00:05:14
Distance: internal 90 external 170
```

The root cause of R3's problem is that R3 has a **network 10.1.13.3 0.0.0.0** configuration command, which does not match R3's 10.1.33.3 G0/1 IP address. If the configuration was not available in the exam question, the **show ip protocols** command could be used to essentially see the same configuration details. In this case, the **show ip protocols** command on R3 lists the text "10.1.13.3/32" as a reference to the contents of the incorrect **network** command's parameters, with "/32" translating to a wildcard mask of 32 binary 0s, or decimal 0.0.0.0.

R3's incorrect configuration means that two actions do not happen on R3's G0/1 interface. First, R3 does not try to find neighbors on its G0/1 interface, which is not a big deal in this case. However, R3 also does not advertise subnet 10.1.33.0/24, the connected subnet off R3's G0/1 interface.

Moving on to R4's problem, Example 11-4 shows why R1 and R2 do not learn R4's 10.1.44.0/24 subnet. In this case, on R4, the engineer could have correctly used a **passive-interface Gigabitethernet0/1** router subcommand because no other routers should exist off R4's G0/1 interface. However, the engineer mistakenly made R4's G0/0 interface passive.

Example 11-4. EIGRP Problems on R4

Click here to view code image

```
R4# show running-config
! lines omitted for brevity
router eigrp 99
passive-interface GigabitEthernet0/0
network 10.0.0.0
auto-summary

R4# show ip eigrp interfaces
EIGRP-IPv4 Interfaces for AS(99)
Xmit Queue PeerQ Mean Pacing Time Multicast Pending
Interface Peers Un/Reliable Un/Reliable SRTT Un/Reliable Flow Timer Routes
Gi0/1 0 0/0 0/0 0 0/1 0 0

R4# show ip protocols | begin Routing for Networks
Routing for Networks:
10.0.0.0
Passive Interface(s):
GigabitEthernet0/0
Routing Information Sources:
Gateway Distance Last Update
```

```
Distance: internal 90 external 170
```

> **Note**
>
> The last command on the example, **show ip protocols | begin Routing for Networks**, lists the command output, but starting with the line with the literal case-sensitive string **Routing for Networks**. You can use this feature with any output from a command when you prefer to view only later lines of the command's output.

To find this mistake without the configuration, Example 11-4 lists two useful commands. R4's **show ip eigrp interfaces** command omits the (G0/0) passive interface, which means that R4 will not attempt to find EIGRP neighbors off that interface. Also, the highlighted part of R4's **show ip protocols** command output lists G0/0 as a passive interface, which again means that R4 does not even attempt to become neighbors with others off its G0/0 interface.

OSPF Interface Troubleshooting

OSPF has the same basic requirements as EIGRP for interfaces, with a few exceptions. First, EIGRP routers need to use the same autonomous system number (ASN) as their neighboring routers, as configured in the **router eigrp** *asn* global configuration command. OSPF routers can use any process ID on the **router ospf** *process-id* command, with no need to match their neighbors. Second, OSPF requires that the interfaces connected to the same subnet be assigned to the same OSPF area, whereas EIGRP has no concept of areas.

Example 11-5 shows a mostly working OSPF internetwork, again based on Figure 11-3. The problem in this case relates to the area design, as shown in the revised version of Figure 11-3, as shown here in Figure 11-4. All subnets should be placed into area 0. However, the engineer made a configuration mistake on R2, putting both its interfaces into area 1. As a result, R2's G0/0 interface breaks the OSPF design rule of being in the same subnet as R1, R3, and R4, but not being in the same OSPF area.

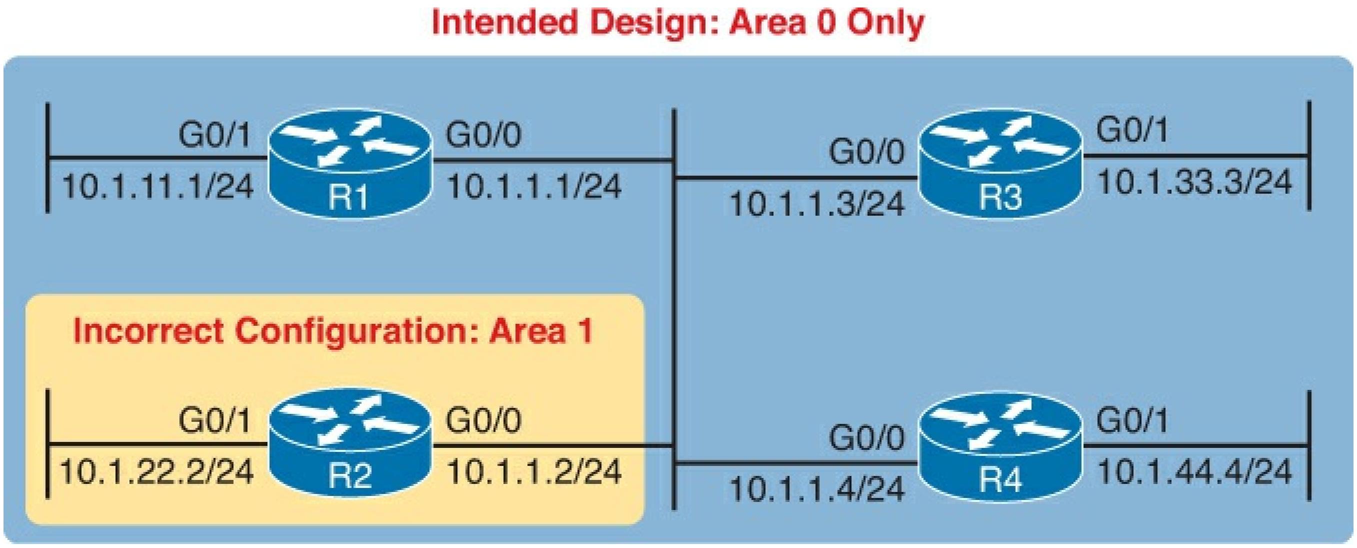


Figure 11-4. Intended Area Design Using Only Area 0, with R2 Breaking the Design

Example 11-5 begins to break down the problem by looking at the status of OSPF on the router interfaces of R1 and R2, using the **show ip ospf interface brief** command.

Example 11-5. show ip interface brief **on R1 and R2**

Click here to view code image

```
R1> show ip ospf interface brief
Interface PID Area IP Address/Mask Cost State Nbrs F/C
Gi0/1 1 0 10.1.11.1/24 1 DR 0/0
Gi0/0 1 0 10.1.1.1/24 1 DROTH 2/2
```

```
! The following command is from R2
R2> show ip ospf interface brief
Interface PID Area IP Address/Mask Cost State Nbrs F/C
Gi0/1 2 1 10.1.22.2/24 1 WAIT 0/0
Gi0/0 2 1 10.1.1.2/24 1 WAIT 0/0
```

From a general perspective, the **show ip ospf interface brief** command lists output similar to the **show ip eigrp interface** command, with one line for each enabled interface. The **show ip ospf interface** command, not shown in the example, lists detailed OSPF information for each interface.

Specific to this problem, the output in Example 11-5 shows that R1 and R2 both have OSPF enabled on both LAN interfaces. However, this command also lists the area number for each interface, with R2 having both LAN interfaces in area 1. Also, these commands repeat the IP address and mask of the interfaces, so together, you can see that R1's 10.1.1.1/24 address is in the same subnet as R2's 10.1.1.2/24 address, putting these two routers in the same subnet but in different OSPF areas.

Example 11-6 shows another way to look at the problem, with the **show ip protocols** commands on both R1 and R2. Because this command lists the OSPF **network** commands in shorthand form, it can point toward a possible configuration error, even if the configuration is not available.

Example 11-6. Finding OSPF Configuration Errors with show ip protocols **R1 and R2**

Click here to view code image

```
R1> show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "ospf 1"
Outgoing update filter list for all interfaces is not set
Incoming update filter list for all interfaces is not set
Router ID 1.1.1.1
Number of areas in this router is 1. 1 normal 0 stub 0 nssa
Maximum path: 4
Routing for Networks:
10.0.0.0 0.255.255.255 area 0
Routing Information Sources:
Gateway Distance Last Update
2.2.2.2 110 00:14:32
3.3.3.3 110 00:14:32
10.1.44.4 110 00:14:42
Distance: (default is 110)

R1> show ip route ospf
! Legend omitted for brevity

10.0.0.0/8 is variably subnetted, 6 subnets, 2 masks
O 10.1.33.0/24 [110/2] via 10.1.1.3, 00:15:32, GigabitEthernet0/0
O 10.1.44.0/24 [110/2] via 10.1.1.4, 00:15:42, GigabitEthernet0/0
```

```
! Now moving to router R2

R2> show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "ospf 2"
Outgoing update filter list for all interfaces is not set
Incoming update filter list for all interfaces is not set
Router ID 2.2.2.2
Number of areas in this router is 1. 1 normal 0 stub 0 nssa
Maximum path: 4
Routing for Networks:
10.0.0.0 0.255.255.255 area 1
Routing Protocol is "ospf 2"
Outgoing update filter list for all interfaces is not set
Incoming update filter list for all interfaces is not set
Router ID 2.2.2.2
Number of areas in this router is 1. 1 normal 0 stub 0 nssa
Maximum path: 4
Routing for Networks:
10.0.0.0 0.255.255.255 area 1
Routing Information Sources:
Gateway Distance Last Update
Distance: (default is 110)

R2>
Nov 15 12:16:39.377: %OSPF-4-ERRRCV: Received invalid packet: mismatched area
ID, from backbone area must be virtual-link but not found from 10.1.1.1,
GigabitEthernet0/0
```

Interestingly, a closer look at R2's **show ip protocols** command output, particularly the highlighted portion, points out the configuration error. As usual, the section with heading "Routing for Networks:" points to a shorthand version of the configuration. In this case, the highlighted phrase "10.0.0.0 0.255.255.255 area 1" is actually the exact syntax of the one **network** command on router R2, minus the word *network*, or **network 10.0.0.0 0.255.255.255 area 1**. Because Figure 11-4 shows the design should put all interfaces in area 0, reconfiguring this command to instead be **network 10.0.0.0 0.255.255.255 area 0** would solve this particular problem.

The end of the example also shows an unsolicited log message generated by router R2, notifying the console user that this router has received a Hello from a router in a different area.

As you check the interfaces, you could also check several other details. It makes sense to go ahead and check the interface IP addresses, masks, and interface status values by using the **show interfaces** and **show ip interface brief** commands. In particular, it is helpful to note which interfaces are up/up because a router will send no packets (including routing protocol packets) out interfaces that are not in an up/up state. These interface verification checks were discussed in detail in Chapter 5, "IPv4 Troubleshooting Part 2," so they are not repeated here.

Neighbor Relationships

This final major section of the chapter examines the large number of facts that each router must check with each potential neighbor before the two routers become neighbors.

At a very basic level, routing protocols can easily create neighbor relationships using a Hello protocol. First, the routing protocol must be enabled on an interface. In addition, interface may not be configured as a passive interface, because that stops the routing protocol from sending the Hello messages.

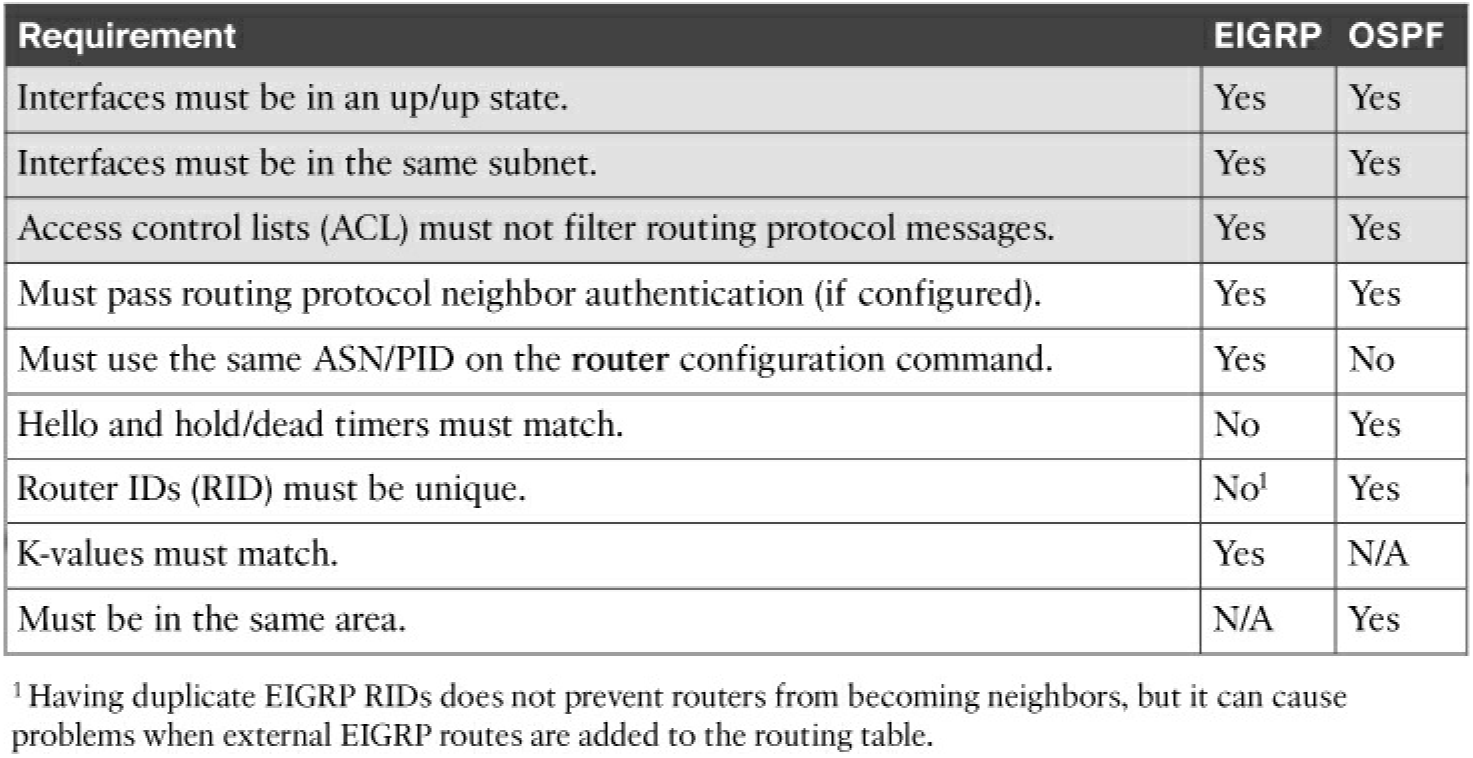
Beyond this basic process, the routing protocols actually check several other parameters to find out whether the routers should become neighbors. Both OSPF and EIGRP use Hello messages, and these messages each list information used to perform some basic verification checks. For example, as just shown in earlier Example 11-5, an OSPF router should not become neighbors with another router in another area because all routers on a common subnet should be in the same OSPF area by design.

After an EIGRP or OSPF router hears a Hello from a new neighbor, the routing protocol examines the information in the Hello, and compares that information with the local router's own settings. If the settings match, great. If not, the routers do not become neighbors. Because there is no formal term for all these items that a routing protocol considers, this book just calls them *neighbor requirements*.

Table 11-2 lists the neighbor requirements for both EIGRP and OSPF. Following the table, the next few pages examine some of these settings for both EIGRP and OSPF, again using examples based on Figure 11-3.

Key Topic

Table 11-2. Neighbor Requirements for EIGRP and OSPF



Requirement	EIGRP	OSPF
Interfaces must be in an up/up state.	Yes	Yes
Interfaces must be in the same subnet.	Yes	Yes
Access control lists (ACL) must not filter routing protocol messages.	Yes	Yes
Must pass routing protocol neighbor authentication (if configured).	Yes	Yes
Must use the same ASN/PID on the **router** configuration command.	Yes	No
Hello and hold/dead timers must match.	No	Yes
Router IDs (RID) must be unique.	No[1]	Yes
K-values must match.	Yes	N/A
Must be in the same area.	N/A	Yes

[1] Having duplicate EIGRP RIDs does not prevent routers from becoming neighbors, but it can cause problems when external EIGRP routes are added to the routing table.

> **Note**
>
> Even though it is important to study and remember the items in this table, when reading this chapter the first time, just keep reading. When later reviewing the chapter or part, make sure you remember the details in the table.

Unlike most of the neighbor requirements listed in Table 11-2, the first three requirements have very little to do with the routing protocols themselves. The two routers must be able to send packets to each other over the physical network to which they are both connected. To do that, the router interfaces must be up/up, and they must be in the same subnet. In addition, the routers must not be using an ACL that filters the routing protocol traffic.

For instance, OSPF sends many messages to the well-known multicast IP addresses 224.0.0.5 and 224.0.0.6, whereas EIGRP uses 224.0.0.10. An ACL command like **access-list 101 deny ip any host 224.0.0.10**, in an inbound ACL on a router interface, would filter incoming EIGRP packets. Or, an ACL command like **access-list 102 deny ospf any any** could filter all OSPF traffic. So, take extra care to watch for ACLs, especially when it seems like all the routing protocol configuration looks good.

In practice, before examining the rest of the details of why two routers do not become neighbors, confirm that the two routers can ping each other on the local subnet. If the ping fails, investigate all the Layer 1, 2, and 3 issues that could prevent the ping from working (such as an interface not being up/up), as covered in Chapters 4, "Troubleshooting IPv4 Routing Part I," and 5, "Troubleshooting IPv4 Routing Part II," of this book and in many chapters of this book and in the ICND1 book.

Now, on to the specific discussions about EIGRP and OSPF. Because the details differ slightly between the two routing protocols, this section first examines EIGRP, followed by OSPF.

> **Note**
>
> This section assumes that the routing protocol has actually been enabled on each required interface, as covered earlier in this chapter in the "Interfaces Enabled with a Routing Protocol" section.

EIGRP Neighbor Verification Checks

Any two EIGRP routers that connect to the same data link, and whose interfaces have been enabled for EIGRP and are not passive, will at least consider becoming neighbors. To quickly and definitively know which potential neighbors have passed all the neighbor requirements for EIGRP, just look at the output of the **show ip eigrp neighbors** command. This command lists only neighbors that have passed all the neighbor verification checks.

Example 11-7 shows an example of the **show ip eigrp neighbors** command, with the four routers from Figure 11-3 again. In this case, all the routers have been configured correctly, so each has a neighbor relationship with the other three routers on the same LAN subnet.

Example 11-7. R1 show ip eigrp neighbors **Command with All Problems Fixed**

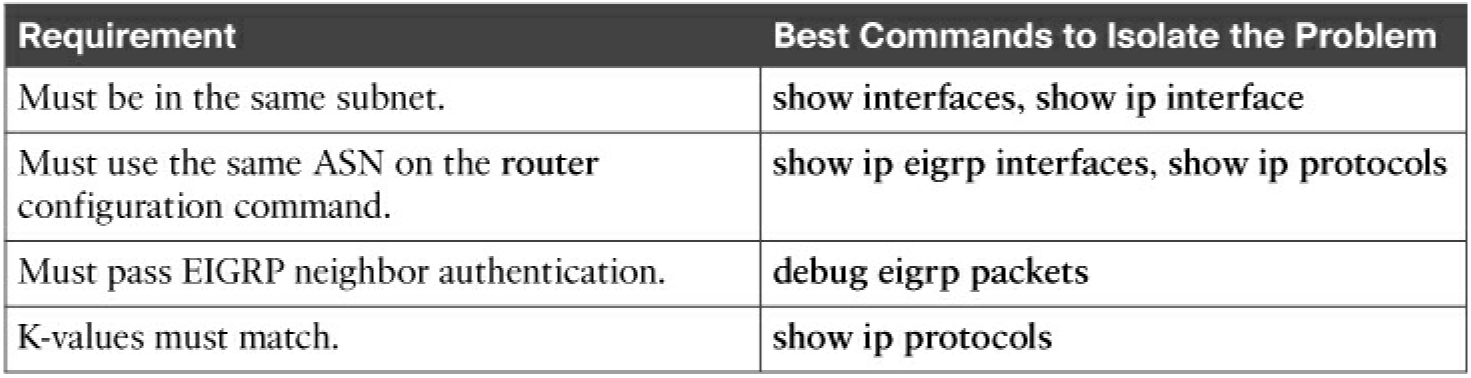
Click here to view code image

```
R1# show ip eigrp neighbors
EIGRP-IPv4 Neighbors for AS(99)
H Address Interface Hold Uptime SRTT RTO Q Seq
(sec) (ms) Cnt Num
1 10.1.1.3 Gi0/0 13 00:00:20 1 100 0 31
2 10.1.1.4 Gi0/0 13 00:00:43 80 480 0 10
0 10.1.1.2 Gi0/0 13 00:13:52 1 100 0 20
```

If the **show ip eigrp neighbors** command does not list one or more expected neighbors, the first problem isolation step should be to find out if the two routers can ping each others' IP addresses on the same subnet. If that works, start looking at the list of neighbor verification checks, as relisted for EIGRP here in Table 11-3. Table 11-3 summarizes the EIGRP neighbor requirements, while noting the best commands with which to determine which requirement is the root cause of the problem.

Key Topic

Table 11-3. EIGRP Neighbor Requirements and the Best show/debug **Commands**



Requirement	Best Commands to Isolate the Problem
Must be in the same subnet.	show interfaces, show ip interface
Must use the same ASN on the router configuration command.	show ip eigrp interfaces, show ip protocols
Must pass EIGRP neighbor authentication.	debug eigrp packets
K-values must match.	show ip protocols

Of the four rows of requirements listed in Table 11-3, the first two have already been discussed; the last two have not.

For EIGRP authentication, EIGRP supports the capability for routers to trust routers as EIGRP neighbors only if the routers share the same security key (password); if that check fails, the neighbor relationship fails. By default, routers do not attempt

EIGRP authentication, which allows the routers to form EIGRP neighbor relationships. If one router uses authentication, and the other does not, they will not become neighbors. If both use authentication, they must use the same authentication key to become neighbors.

The last item in the table, EIGRP K-values, refers to the EIGRP metric components and the metric calculation. These K-values are variables that basically enable or disable the use of the different components in the EIGRP composite metric. Cisco recommends leaving these values at their default settings, using only bandwidth and delay in the metric calculation. The K-value settings must match before two routers will become neighbors; you can check the K-values on both routers with the **show ip protocols** command.

EIGRP Neighbor Troubleshooting Example

Example 11-8 shows three problems that can cause EIGRP routers to fail to become neighbors. This example uses the usual design for this chapter, as repeated in Figure 11-5. The figure shows the same routers, and same interfaces, but with the following problems:

- R2 has been configured with IP address 10.1.2.2/24 in a different subnet than R1, R3, and R4.
- R3 has been configured to use ASN 199 with the **router eigrp 199** command instead of ASN 99, as used on the other three routers.
- R4 has been configured to use message digest 5 (MD5) authentication, whereas the other routers use no authentication.

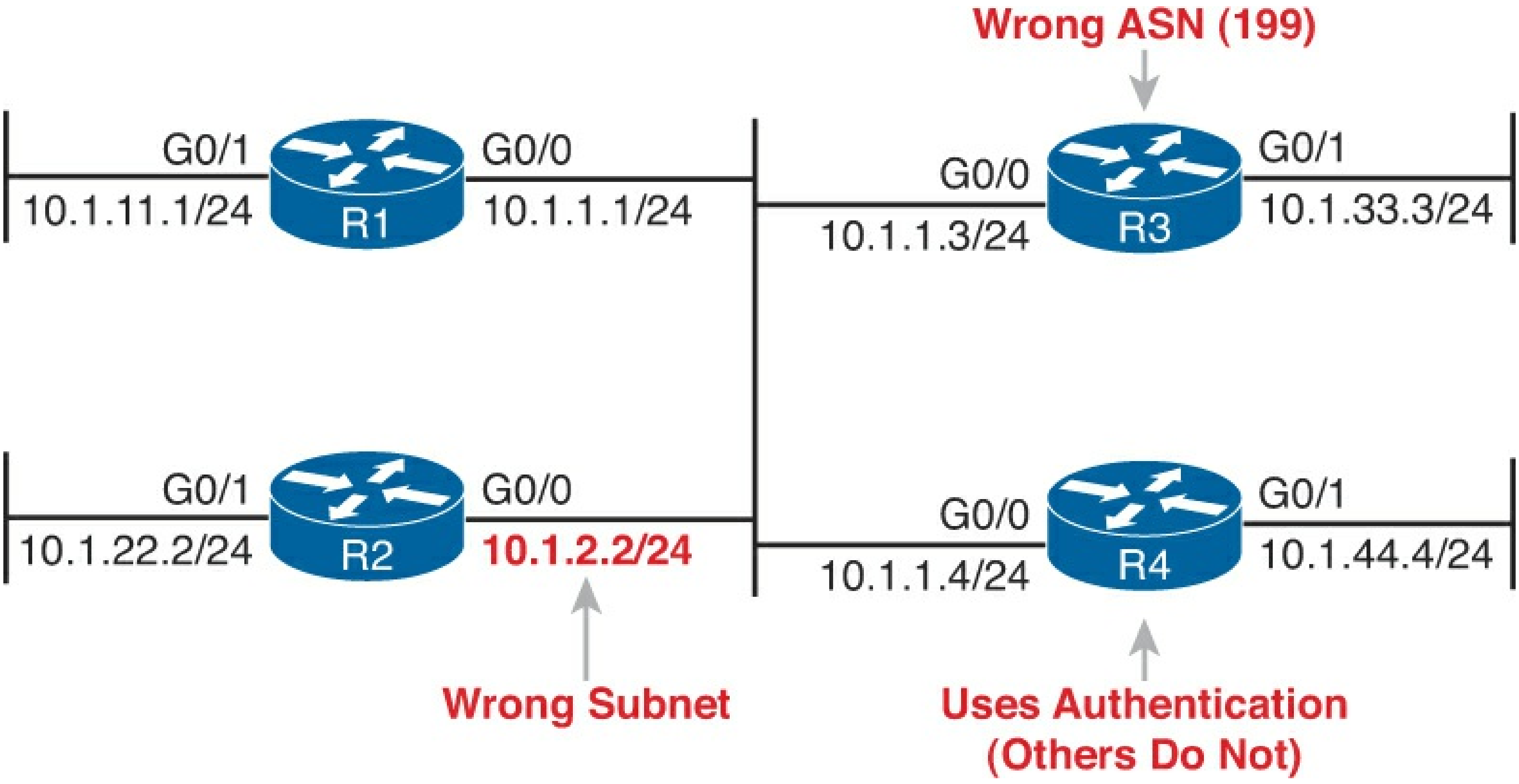


Figure 11-5. Summary of Problems That Prevent EIGRP Neighbors on the Central LAN

R1 can actually detect two of the problems using local commands and messages, as shown in Example 11-8. R1 generates an unsolicited log message for the mismatched subnet problem, and a **debug** command on R1 can reveal the authentication failure. The example shows some running commentary inside the example.

Example 11-8. Common Problems Preventing the Formation of EIGRP Neighbors (R1)

Click here to view code image

```
! First, R1 has no neighbor relationships yet. R1 uses ASN (process) 99.
R1# show ip eigrp neighbors
EIGRP-IPv4 Neighbors for AS(99)

R1#
! Next, R1 generates a log message, which shows up at the console, stating
! that the router with IP address 10.1.2.2 is not on the same subnet as R1.
!
*Nov 15 16:19:14.740: %DUAL-6-NBRINFO: EIGRP-IPv4 99: Neighbor 10.1.2.2
(GigabitEthernet0/0) is blocked: not on common subnet (10.1.1.1/24)

! Next, R1 enables a debug that shows messages for each packet received from R4,
! which uses the wrong password (authentication key string)
!
R1# debug eigrp packets
EIGRP Packets debugging is on
(UPDATE, REQUEST, QUERY, REPLY, HELLO, IPXSAP, PROBE, ACK, STUB, SIAQUERY,
SIAREPLY)
R1#

*Nov 15 16:20:30.865: EIGRP: Gi0/0: ignored packet from 10.1.1.4, opcode = 5 (authentication off or key-chain
missing)
```

Example 11-8 shows some evidence of the mismatched subnet with R2, and the invalid authentication problem with R4, but it does not show any information about the incorrect ASN configured on R3. Example 11-9 lists excerpts from two **show** commands on R3, both of which identify the ASN configured on that router. By using these same commands on all the routers, you could note that R1, R2, and R4 use ASN 99, whereas R3 uses 199, as shown in Example 11-9.

Example 11-9. Displaying the Incorrect ASN (199) on R3

Click here to view code image

```
R3# show ip protocols
Routing Protocol is "eigrp 199"
!
! The first line of output from show ip eigrp interfaces lists ASN 199
!
R3# show ip eigrp interfaces
EIGRP-IPv4 Interfaces for AS(199)
Xmit Queue Mean Pacing Time Multicast Pending
Interface Peers Un/Reliable SRTT Un/Reliable Flow Timer Routes
Gi0/0 0 0/0 0 0/1 0 0
Gi0/1 0 0/0 0 0/1 0 0
```

OSPF Neighbor Troubleshooting

Similar to EIGRP, a router's **show ip ospf neighbor** command lists all the neighboring routers that have met all the requirements to become an OSPF neighbor as listed in Table 11-2. So, the first step in troubleshooting OSPF neighbors is to look at the list of neighbors.

Example 11-10 lists the output of a **show ip ospf neighbor** command on router R2, from Figure 11-4. All four routers sit on the same LAN subnet, in area 0, with correct configurations, so all four routers form a valid OSPF neighbor relationship.

Example 11-10. Normal Working show ip ospf neighbors **Command on Router R2**

Click here to view code image

```
R2# show ip ospf neighbor

Neighbor ID Pri State Dead Time Address Interface
1.1.1.1 1 FULL/BDR 00:00:37 10.1.1.1 GigabitEthernet0/0
3.3.3.3 1 2WAY/DROTHER 00:00:37 10.1.1.3 GigabitEthernet0/0
4.4.4.4 1 FULL/DR 00:00:31 10.1.1.4 GigabitEthernet0/0
```

First, note that the neighbor IDs, listed in the first column, identify neighbors by their router ID (RID). For this example network, all four routers use an easily guessed RID. Further to the right, the Address column lists the interface IP address used by that neighbor on the common subnet.

A brief review of OSPF neighbor states (as explained in Chapter 8) can help you understand a few of the subtleties of the output in the example. A router's listed status for each of its OSPF neighbors—the neighbor's state—should settle into either a 2-way or full state under normal operation. For neighbors that do not need to directly exchange their databases, typically two non-designated router (DR) routers on a LAN, the routers should settle into a 2-way neighbor state. In most cases, two neighboring routers need to directly exchange their full link-state databases (LSDB) with each other. As soon as that process has been completed, the two routers settle into a full neighbor state.

In Example 11-10, router R4 is the DR, and R1 is the backup DR (BDR), so R2 and R3 (as non-DRs) do not need to directly exchange routes. Therefore, R2's neighbor state for R3 (RID 3.3.3.3) in Example 11-10 is listed as 2-way.

Note

Notably, OSPF neighbors do not have to use the same process ID on the **router ospf** *process-id* command to become neighbors. In Example 11-10, all four routers use different PIDs.

If the **show ip ospf neighbor** command does not list one or more expected neighbors, you should confirm, even before moving on to look at OSPF neighbor requirements, that the two routers can ping each other on the local subnet. But if the two neighboring routers can ping each other, and the two routers still do not become OSPF neighbors, the next step is to examine each of the OSPF neighbor requirements. Table 11-4 summarizes the requirements, listing the most useful commands with which to find the answers.

Key Topic

Table 11-4. OSPF Neighbor Requirements and the Best show**/**debug **Commands**

Requirement	Best Commands to Isolate the Problem
Must be in the same subnet.	**show interfaces, debug ip ospf hello**
Must pass any neighbor authentication.	**show ip ospf interface, debug ip ospf adj**
Hello and dead timers must match.	**show ip ospf interface, debug ip ospf hello**
Must be in the same area.	**show ip ospf interface brief, debug ip ospf adj**
RIDs must be unique.	**show ip ospf**

This topic looks at a couple of OSPF neighbor problems using the usual four-router network from Figure 11-4 is used, with all interfaces in area 0. However, the following problems have been introduced into the design:

- R2 has been configured with both LAN interfaces in area 1, whereas the other three routers' G0/0 interfaces are assigned to area 0.
- R3 is using the same RID (1.1.1.1) as R1.
- R4 has been configured with a Hello/Dead timer of 5/20 on its G0/0 interface, instead of the 10/40 used (by default) on R1, R2, and R3.

Figure 11-6 shows these same problems for reference.

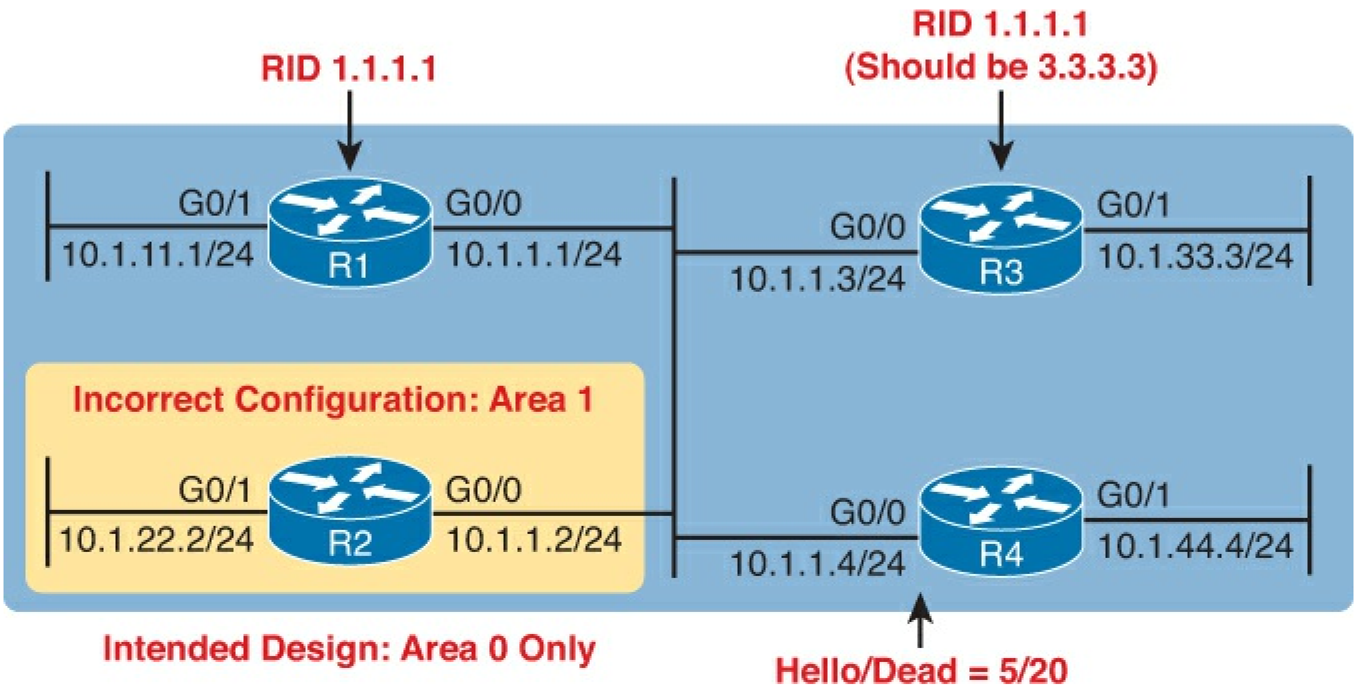


Figure 11-6. Summary of Problems That Prevent OSPF Neighbors on the Central LAN

Finding Area Mismatches

Earlier in this chapter, the "OSPF Interface Troubleshooting" section showed how to use the **show ip ospf interface** command to list the area numbers and find OSPF area mismatches. This next topic shows how to see that same issue using the **debug ip ospf adj** command, as shown in Example 11-11. This command lists messages related to OSPF neighbor adjacency events, shows messages that identify the area mismatch (with R2).

Example 11-11. Finding Mismatched Area Problem with R1 debug

[Click here to view code image](#)

```
R1# debug ip ospf adj
OSPF adjacency events debugging is on
R1#
*Nov 15 13:42:02.288: OSPF-1 ADJ Gi0/0: Rcv pkt from 10.1.1.2, area 0.0.0.0, mis-
matched area 0.0.0.1 in the header
R1#
R1# undebug all
All possible debugging has been turned off
```

As noted in Table 11-4, the **debug ip ospf adj** command helps troubleshoot mismatched OSPF area problems and authentication problems. The first highlighted messages in the example lists shorthand about a received packet ("Rcv pkt") from 10.1.1.2, which is R2's IP address. The rest of the message mentions R1's area (0.0.0.0), and the area claimed by the other router (0.0.0.1). (Note that these messages list the 32-bit area number as a dotted-decimal number.)

Finding Duplicate OSPF Router IDs

Next, Example 11-12 shows R1 and R3 both trying to use RID 1.1.1.1. Interestingly, both routers automatically generate a log message for the duplicate OSPF RID problem between R1 and R3; the end of Example 11-12 shows one such message. For the exams, just use the **show ip ospf** commands on both R3 and R1 to easily list the RID on each router, noting that they both use the same value.

Example 11-12. Comparing OSPF Router IDs on R1 and R3

[Click here to view code image](#)

```
! Next, on R3: ! R3 lists the RID of 1.1.1.1
!
R3# show ip ospf
Routing Process "ospf 3" with ID 1.1.1.1
Start time: 00:00:37.136, Time elapsed: 02:20:37.200
! lines omitted for brevity
```

```
! Back to R1: R1 also uses RID 1.1.1.1

R1# show ip ospf
Routing Process "ospf 1" with ID 1.1.1.1
Start time: 00:01:51.864, Time elapsed: 12:13:50.904
Supports only single TOS(TOS0) routes
Supports opaque LSA
Supports Link-local Signaling (LLS)
Supports area transit capability
Supports NSSA (compatible with RFC 3101)
Event-log enabled, Maximum number of events: 1000, Mode: cyclic
Router is not originating router-LSAs with maximum metric
Initial SPF schedule delay 5000 msecs
Minimum hold time between two consecutive SPFs 10000 msecs
Maximum wait time between two consecutive SPFs 10000 msecs
Incremental-SPF disabled
Minimum LSA interval 5 secs
Minimum LSA arrival 1000 msecs
LSA group pacing timer 240 secs
Interface flood pacing timer 33 msecs
Retransmission pacing timer 66 msecs
Number of external LSA 0. Checksum Sum 0x000000
Number of opaque AS LSA 0. Checksum Sum 0x000000
Number of DCbitless external and opaque AS LSA 0
Number of DoNotAge external and opaque AS LSA 0
Number of areas in this router is 1. 1 normal 0 stub 0 nssa
Number of areas transit capable is 0
External flood list length 0
IETF NSF helper support enabled
Cisco NSF helper support enabled
Reference bandwidth unit is 100 mbps
Area BACKBONE(0) (Inactive)
```

```
Number of interfaces in this area is 3
Area has no authentication
SPF algorithm last executed 00:52:42.956 ago
SPF algorithm executed 9 times
Area ranges are
Number of LSA 1. Checksum Sum 0x00C728
Number of opaque link LSA 0. Checksum Sum 0x000000
Number of DCbitless LSA 0
Number of indication LSA 0
Number of DoNotAge LSA 0
Flood list length 0

*May 29 00:01:25.679: %OSPF-4-DUP_RTRID_NBR: OSPF detected duplicate router-id
1.1.1.1 from 10.1.1.3 on interface GigabitEthernet0/0
```

First, focus on the problem: the duplicate RIDs. The first line of the **show ip ospf** command on the two routers quickly shows the duplicate use of 1.1.1.1. To solve the problem, assuming R1 should use 1.1.1.1 and R3 should use another RID (maybe 3.3.3.3), change the RID on R3, and restart the OSPF process. To do so, use the **router-id 3.3.3.3** OSPF subcommand and use the EXEC mode command **clear ip ospf process**.

Also, take a moment to read over the log message generated on each router when a duplicate RID exists.

Finally, note that the **show ip ospf** commands in Example 11-12 also show a common false positive for a root cause of OSPF neighbor problems. OSPF PIDs—the number of the **router ospf** command—do not have to match. Note that in Example 11-12 that same first line of output shows that R3 uses the **router ospf 3** command, per the phrase “Process ospf 3,” whereas R1 uses the **router ospf 1** command, as noted with the phrase “Process ospf 1.” These mismatched numbers are not a problem.

Finding OSPF Hello and Dead Timer Mismatches

Finally, consider the problem created on R4, with the configuration of a different Hello and dead timer as compared with the default settings on R1, R2, and R3. Whereas EIGRP allows neighbors to use a different Hello timer, OSPF does not, so this mismatch prevents R4 from becoming neighbors with any of the other three OSPF routers.

Example 11-13 shows the easiest way to find the mismatch, using the **show ip ospf interface** command on both R1 and R4. This command lists the Hello and dead timer for each interface, as highlighted in the example. Note that R1 uses 10 and 40 (Hello and dead), whereas R4 uses 5 and 20.

Example 11-13. Finding Mismatched Hello/Dead Timers

Click here to view code image

```
R1# show ip ospf interface G0/0
GigabitEthernet0/0 is up, line protocol is up
Internet Address 10.1.1.1/24, Area 0, Attached via Network Statement
Process ID 1, Router ID 1.1.1.1, Network Type BROADCAST, Cost: 1
Topology-MTID Cost Disabled Shutdown Topology Name
0 1 no no Base
Transmit Delay is 1 sec, State DR, Priority 1
Designated Router (ID) 1.1.1.1, Interface address 10.1.1.1
No backup designated router on this network
Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
! lines omitted for brevity
```

```
! Moving on to R4 next
!
R4# show ip ospf interface Gi0/0
GigabitEthernet0/0 is up, line protocol is up
Internet Address 10.1.1.4/24, Area 0, Attached via Network Statement
Process ID 4, Router ID 10.1.44.4, Network Type BROADCAST, Cost: 1
Topology-MTID Cost Disabled Shutdown Topology Name
0 1 no no Base
Transmit Delay is 1 sec, State DR, Priority 1
Designated Router (ID) 10.1.44.4, Interface address 10.1.1.4
No backup designated router on this network
Timer intervals configured, Hello 5, Dead 20, Wait 20, Retransmit 5
! lines omitted for brevity
```

The **debug ip ospf hello** command can also uncover this problem because it lists a message for each Hello that reveals the Hello/dead timer mismatch, as shown in Example 11-14.

Example 11-14. Finding Mismatched Hello/Dead Timers

Click here to view code image

```
R1# debug ip ospf hello
OSPF hello events debugging is on
R1#
*Nov 15 14:05:10.616: OSPF-1 HELLO Gi0/0: Rcv hello from 10.1.44.4 area 0 10.1.1.4
*Nov 15 14:05:10.616: OSPF-1 HELLO Gi0/0: Mismatched hello parameters from 10.1.1.4
*Nov 15 14:05:10.616: OSPF-1 HELLO Gi0/0: Dead R 20 C 40, Hello R 5 C 10 Mask R
255.255.255.0 C 255.255.255.0
```

Although debug messages can be a little difficult to understand, a few comments make the meaning of these messages much clearer. The highlighted message uses a *C* to mean "configured value"—in other words, the value on the local router, or R1 in this case. The *R* in the message means "received value," or the value listed in the received Hello. In this case

- "Dead R 20 C 40" means that R1 received a Hello with a dead timer set to 20, while R1's configured value is set to 40.
- "Hello R 5 C 10" means that R1 received a Hello with the Hello timer set to 5, while R1's configured value is set to 10.

Note that any IP subnet mismatch problems could also be found with this same debug, based on the received and configured subnet masks.

Other OSPF Issues

OSPFv2 can have a few other problems, two of which Cisco included in the OSPF troubleshooting exam topics. This last short discussion in this chapter looks at these two additional topics: the OSPF network type and the interface maximum transmission unit (MTU) size.

Mismatched OSPF Network Types

OSPF defines a concept for each interface called a network type. The OSPF *network type* tells OSPF some ideas about the data link to which the interface connects. In particular, the network type tells a router:

- Whether the router can dynamically discover neighbors on the attached link (or not)
- Whether to elect a DR and BDR (or not)

So far in this book, only two OSPF network types have been used based on default settings. Serial interfaces that use some point-to-point data link protocol, like HDLC or PPP, default to use an OSPF network type of *point-to-point*. Ethernet interfaces default to use an OSPF network type of *broadcast*. Both types allow the routers to dynamically discover the neighboring OSPF routers, but only the broadcast network type causes the router to use a DR/BDR.

The **show ip ospf interface** command lists an interface's current OSPF network type. Example 11-15 shows router R1, from the earlier examples, with a network type of "broadcast" on its G0/0 interface.

Example 11-15. Displaying the OSPF Network Type on an Interface

Click here to view code image

```
R1# show ip ospf interface g0/0
GigabitEthernet0/0 is up, line protocol is up
Internet Address 10.1.1.1/24, Area 0, Attached via Network Statement
Process ID 1, Router ID 1.1.1.1, Network Type BROADCAST, Cost: 1
! Lines omitted for brevity
```

It is possible to change the OSPF network type on an interface and, by making poor choices about the settings on neighboring routers, to prevent the routers from becoming OSPF neighbors. Normally, engineers either leave this setting at its default value, or they change the setting for all routers on the same link. However, by choosing poorly, and using different network types on different neighboring routers, problems can occur.

For instance, if routers R1 and R2 from the sample internetwork used in this chapter still connect to the same VLAN, both using their G0/0 interfaces, they both by default use OSPF network type broadcast. These routers work best on their Ethernet interfaces with an OSPF network type of broadcast. As a result, both dynamically learn about each other as an OSPF router, and they both try to use a DR/BDR. However, if R1 was changed to use network type point-to-point on its G0/0 interface instead, problems occur. The result? The routers actually still become neighbors, but fail to exchange their LSDBs, as shown by R1 no longer having any OSPF-learned routes in Example 11-16

Example 11-16. Mismatched OSPF Network Types Causing a Failure to Exchange LSDBs

Click here to view code image

```
R1# configure terminal
```

```
Enter configuration commands, one per line. End with CNTL/Z.
R1(config)# interface gigabitethernet0/0
R1(config-if)# ip ospf network point-to-point
R1(config-if)# ^Z
R1#
R1# show ip route ospf
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
E1 - OSPF external type 1, E2 - OSPF external type 2
i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
ia - IS-IS inter area, * - candidate default, U - per-user static route
o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
+ - replicated route, % - next hop override

Gateway of last resort is not set

R1#
! Lines omitted for brevity
```

Note that in production networks you want to use the default OSPF network types unless you have a reason to override the values. Chapter 14, “Implementing Frame Relay,” shows the one common case of configuring a nondefault value when using one particular style of Frame Relay configuration.

Mismatched MTU Settings

The MTU size defines a per-interface setting used by the router for its Layer 3 forwarding logic, defining the largest network layer packet that the router will forward out each interface. For instance, the IPv4 MTU size of an interface defines the maximum size IPv4 packet that the router can forward out an interface.

Routers often use a default mtu size of 1500 bytes, with the ability to set the value as well. The **ip mtu** *size* interface subcommand defines the IPv4 mtu setting, and the **ipv6 mtu** *size* command sets the equivalent for IPv6 packets.

In an odd twist, two OSPFv2 routers can actually become OSPF neighbors, and reach 2-way state, even if they happen to use different IPv4 mtu settings on their interfaces. However, they fail to exchange their LSDBs. Eventually, after trying and failing to exchange their LSDBs, the neighbor relationship also fails.

The concepts behind what happens with an MTU mismatch work the same with both OSPFv2 and OSPFv3. In Chapter 17, “Implementing OSPF for IPv6,” the “Troubleshooting OSPFv3 LSAs” section shows an example of this particular problem with OSPFv3. Read that section for a little more detail about this issue.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 11-5 lists these key topics and where each is discussed.

Table 11-5. Key Topics for Chapter 11

Key Topic Element	Description	Page Number
List	Two things that happen when EIGRP or OSPF is enabled on a router's interface	326
Table 11-1	Three commands that enable you to determine on which interfaces EIGRP or OSPF has been enabled	326
Table 11-2	Neighbor requirements for both EIGRP and OSPF	336
Table 11-3	EIGRP neighbor requirements and useful commands to isolate that requirement as the root cause of a neighbor problem	337
Table 11-4	The same information as Table 11-3, but for OSPF	340

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix D, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix E, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Command Reference to Check Your Memory

Although you should not necessarily memorize the information in the tables in this section, does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table, read the descriptions on the right side, and see if you remember the command.

Table 11-6. Chapter 11 Configuration Command Reference

Command	Description
ip hello-interval eigrp *as-number timer-value*	Interface subcommand that sets the EIGRP Hello interval for that EIGRP process
ip hold-time eigrp *as-number seconds*	Interface subcommand that sets the EIGRP hold time for the interface
ip ospf hello-interval *seconds*	Interface subcommand that sets the interval for periodic Hellos
ip ospf dead-interval *number*	Interface subcommand that sets the OSPF dead timer
passive-interface *type number*	Router subcommand, for both OSPF and EIGRP that tells the routing protocol to stop sending Hellos and stop trying to discover neighbors on that interface

Table 11-7. Chapter 11 show **Command Reference**

Command	Description
show ip protocols	Shows routing protocol parameters and current timer values, including an effective copy of the routing protocols' **network** commands and a list of passive interfaces
show ip eigrp interfaces	Lists the interfaces on which EIGRP has been enabled for each EIGRP process, except passive interfaces
show ip route eigrp	Lists only EIGRP-learned routes from the routing table
show ip eigrp neighbors	Lists EIGRP neighbors and status
show ip ospf interface brief	Lists the interfaces on which the OSPF protocol is enabled (based on the **network** commands), including passive interfaces
show ip ospf interface [*type number*]	Lists detailed OSPF settings for all interfaces, or the listed interface, including Hello and Dead timers and OSPF area
show ip route ospf	Lists routes in the routing table learned by OSPF
show ip ospf neighbor	Lists neighbors and current status with neighbors, per interface
show ip ospf	Lists a group of messages about the OSPF process itself, listing the OSPF Router ID in the first line
show interfaces	Lists a long set of messages, per interface, that lists configuration, state, and counter information
show interfaces description	Lists one line of output per interface with brief status information

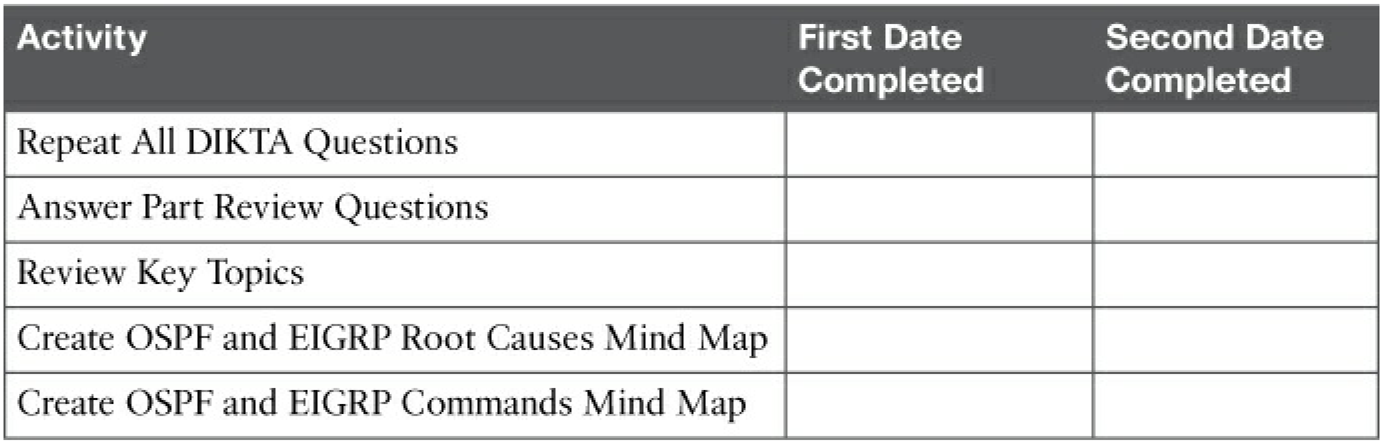
Table 11-8. Chapter 11 debug **Command Reference**

Command	Description
debug eigrp packets	Lists log messages for EIGRP packets that flow in and out of the router
debug ip ospf adj	Issues log messages for adjacency events, meaning events related to routers becoming neighbors
debug ip ospf events	Issues log messages for each action taken by OSPF, including the receipt of messages
debug ip ospf packet	Issues log messages describing the contents of all OSPF packets
debug ip ospf hello	Issues log messages describing Hellos and Hello failures
undebug all	EXEC command used to disable all current debugs

Part III Review

Keep track of your part review progress with the checklist in Table P3-1. Details about each task follow the table.

Table P3-1. Part III Part Review Checklist



Activity	First Date Completed	Second Date Completed
Repeat All DIKTA Questions		
Answer Part Review Questions		
Review Key Topics		
Create OSPF and EIGRP Root Causes Mind Map		
Create OSPF and EIGRP Commands Mind Map		

Repeat All DIKTA Questions

For this task, answer the "Do I Know This Already?" questions again for the chapters in Part I of this book using the PCPT software. See the section "How to View Only DIKTA Questions by Part" in the Introduction to this book to learn how to make the PCPT software show you DIKTA questions for this part only.

Answer Part Review Questions

For this task, answer the Part Review questions for this part of the book using the PCPT software. See the section "How to View Only DIKTA Questions by Part" in the Introduction to this book to learn how to make the PCPT software show you DIKTA questions for this part only.

Key Topic

Review Key Topics

Browse back through the chapters and look for the Key Topic icons. If you do not remember some details, take the time to reread those topics.

Create OSPF and EIGRP Root Causes Mind Map

Chapter 11, "Troubleshooting IPv4 Routing Protocols," focuses on how to troubleshoot problems with both Open Shortest Path First (OSPF) and Enhanced Interior Gateway Routing Protocol (EIGRP), specifically related to interfaces and to neighbor relationships. For this first Part Review mind map, work through all the items you can think of that can fail and cause a problem that prevents a routing protocol from working in IPv4 internetworks like those discussed in this part of the book. In other words, think about the root causes. Then organize those into a mind map.

To organize the mind map, start by just listing whatever comes to mind. Then, once you see several root causes that are related, group those root causes by whatever category comes to mind. There is no right or wrong organization to the root causes.

For instance, you might note root causes, like a shutdown LAN interface on a router or mismatched IP addresses (not in the same subnet). Then you might categorize those as "IP Connectivity on Same Subnet" or "Pingable Same Subnet," as shown in Figure P3-1.

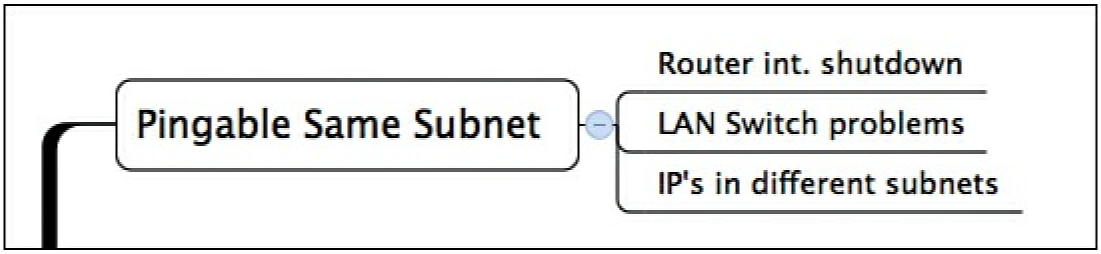


Figure P3-1. Subset Example of the IPv4 Routing Protocol Root Cause Mind Map

> **Note**
>
> For more information about mind mapping, see the section "About Mind Maps" in the Introduction to this book.

Create OSPF and EIGRP Commands Mind Map

This part also discussed both OSPF and EIGRP configuration and verification. Create a command mind map, like in many other part reviews. The first level of organization should be for OSPF versus EIGRP, then for configuration versus verification. Inside the verification area, further organize the commands similar to the organization in Chapter 10, "Implementing EIGRP for IPv4," with commands related to interfaces, neighbors, topology, and routes.

DVD Appendix F, "Mind Map Solutions," lists sample mind map answers, but as usual, your mind maps can and will look different.

Part IV: Wide-Area Networks

Chapter 12: Implementing Point-to-Point WANs

Chapter 13: Understanding Frame Relay Concepts

Chapter 14: Implementing Frame Relay

Chapter 15: Identifying Other Types of WANs

Part IV Review

The world of networking offers a large variety of WAN options. Part IV of this book looks at two traditional options in enough depth to help you comfortably implement the features in Cisco routers: point-to-point WANs (Chapter 12) and Frame Relay (Chapters 13 and 14). Chapter 15 then takes a broad look at a large variety of other WAN options, to enough depth so that you can recognize the main features of each of the technologies.

Chapter 12. Implementing Point-to-Point WANs

This chapter covers the following exam topics:

IP Routing Technologies

Configure and verify operation status of a serial interface

WAN Technologies

Configure and verify a basic WAN serial connection

Configure and verify a PPP connection between Cisco routers

Identify Different WAN Technologies

- T1 / E1

Troubleshooting

Troubleshoot and Resolve WAN implementation issues

- Serial Interfaces
- PPP

Leased-line WANs—also known as serial links—require much less thought than many other topics, at least to the depth required for the CCENT and CCNA exams. That simplicity allows the Cisco exams to discuss leased lines briefly for the ICND1 exam, while using leased lines as part of larger discussions of IP routing.

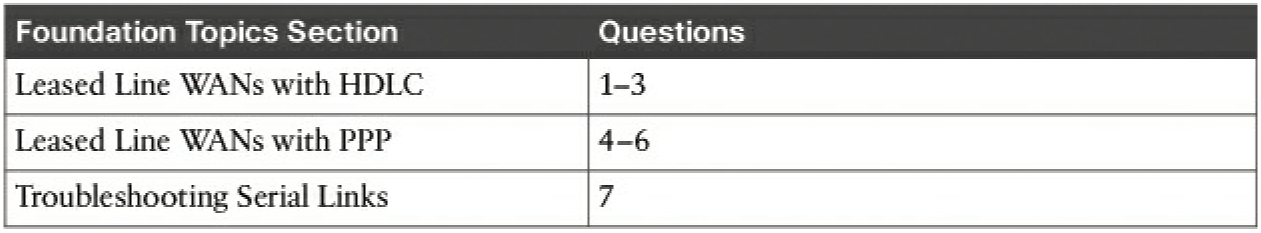
This chapter finally takes the discussion of leased-line WANs deeper than has been discussed so far. This chapter briefly repeats the leased line concepts from the ICND1 book, to lay a foundation to discuss other concepts. More important, this chapter looks at the configuration, verification, and troubleshooting steps for leased lines that use the familiar High-level Data Link Control (HDLC) data-link protocol and the Point-to-Point Protocol (PPP).

This chapter breaks the material down into three major sections. The first looks at leased line WANS that use HDLC, by reviewing and adding details about the physical links themselves, along with HDLC (and related) configuration. The second major section discusses PPP, an alternate data-link protocol that you can use instead of HDLC, with a focus on concepts and configuration. The final major section then discusses typical root causes of serial link problems and how to find those problems.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 12-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Leased Line WANs with HDLC	1–3
Leased Line WANs with PPP	4–6
Troubleshooting Serial Links	7

1. In the cabling for a leased line, which of the following usually connects to a four-wire line provided by a telco?
   - **a.** Router serial interface without internal CSU/DSU
   - **b.** CSU/DSU
   - **c.** Router serial interface with internal transceiver
   - **d.** Switch serial interface
2. Which of the following fields in the HDLC header used by Cisco routers does Cisco add beyond the ISO standard HDLC?
   - **a.** Flag
   - **b.** Type
   - **c.** Address
   - **d.** FCS
3. Two routers connect with a serial link, each using their S0/0/0 interface. The link is currently working using PPP. The network engineer wants to migrate to use the Cisco proprietary HDLC that includes a protocol type field. Which of the following commands can be used to migrate to HDLC successfully? (Choose two answers.)
   - **a. encapsulation hdlc**
   - **b. encapsulation cisco-hdlc**
   - **c. no encapsulation ppp**
   - **d. encapsulation-type auto**
4. Which of the following PPP authentication protocols authenticates a device on the other end of a link without sending

any password information in clear text?

a. MD5

b. PAP

c. CHAP

d. DES

5. Two routers have no initial configuration whatsoever. They are connected in a lab using a DTE cable connected to R1 and a DCE cable connected to R2, with the DTE and DCE cables then connected to each other. The engineer wants to create a working PPP link by configuring both routers. Which of the following commands are required in the R1 configuration for the link to reach a state in which R1 can ping R2's serial IP address, assuming that the physical back-to-back link physically works? (Choose two answers.)

a. encapsulation ppp

b. no encapsulation hdlc

c. clock rate

d. ip address

6. Consider the following excerpt from the output of a **show** command:

Click here to view code image

```
Serial0/0/1 is up, line protocol is up
Hardware is GT96K Serial
Internet address is 192.168.2.1/24
MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,
reliability 255/255, txload 1/255, rxload 1/255
Encapsulation PPP, LCP Open
Open: CDPCP, IPCP, loopback not set
```

Which of the following are true about this router's S0/0/1 interface? (Choose two answers.)

a. The interface is using HDLC.

b. The interface is using PPP.

c. The interface currently cannot pass IPv4 traffic.

d. The link should be able to pass PPP frames at the present time.

7. Consider the following excerpt from the output of a **show interfaces** command on an interface configured to use PPP:

```
Serial0/0/1 is up, line protocol is down
Hardware is GT96K Serial
Internet address is 192.168.2.1/24
```

A ping of the IP address on the other end of the link fails. Which of the following are reasons for the failure, assuming that the problem listed in the answer is the only problem with the link? (Choose two answers.)

a. The CSU/DSU connected to the other router is not powered on.

b. The IP address on the router at the other end of the link is not in subnet 192.168.2.0/24.

c. CHAP authentication failed.

d. The router on the other end of the link has been configured to use HDLC.

e. None of the above.

Answers to the "Do I Know This Already?" quiz:

1 B **2** B **3** A and C **4** C **5** A and D **6** B and D **7** C and D

Foundation Topics

Leased Line WANs with HDLC

A physical leased line WAN works a lot like with an Ethernet crossover cable connecting two routers, but with no distance limitations. As shown in Figure 12-1, each router can send at any time (full duplex). The speed is also symmetric, meaning that both routers send bits at the same speed.

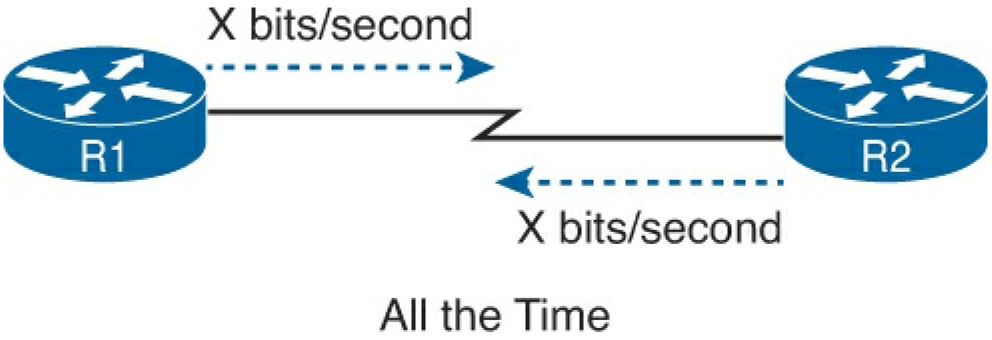


Figure 12-1. Leased Line: Same Speed, Both Directions, Always On

Although the leased line provides a physical layer bit transmission facility, routers also need to use a data link protocol on the WAN link to send bits over the link. The story should be familiar by now: routers receive frames in LAN interfaces, and then the router deencapsulates the network layer packet. Before forwarding the packet, the router encapsulates the packet inside a WAN data link protocol like High-level Data Link Control (HDLC), as shown at Step 2 of Figure 12-2. (Note that the figure does not bother to show the data link trailers in each frame, but each frame does indeed have both a data link header and trailer.)

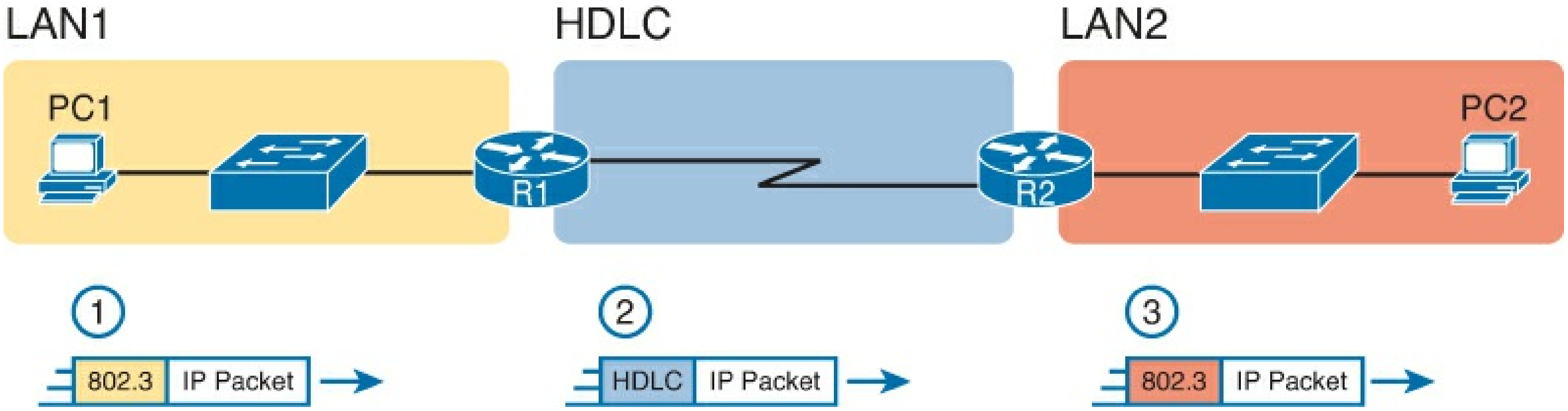


Figure 12-2. Routers and Their Use of HDLC to Encapsulate Packets

These first two figures review some of the Layer 1 and Layer 2 details, respectively, of leased-line WANs. This first major section of this chapter begins by discussion these links again, first with the Layer 1 details, followed by the Layer 2 details. This section ends with an explanation of HDLC configuration details.

Note

The topics from here up to the "HDLC Configuration" section repeat some concepts from the ICND1 book and the ICND1 exam. For those of you who remember the details of leased lines well, as discussed in Chapter 3 of the ICND1 book, you might want to skim the topics of this chapter up to the heading "HDLC Configuration."

Layer 1 Leased Lines

Leased lines have been around a long time, roughly 20 years longer than LANs. However, they still exist today as a WAN service.

As a result of their long history in the market, the networking world has used a large number of different terms. First, the term *leased line* refers to the fact that the company using the leased line does not own the line, but instead pays a monthly lease fee to use it. Often, you lease the service from a telephone company, or *telco*. However, many people today use the generic term *service provider* to refer to a company that provides any form of WAN connectivity, including Internet services. Table 12-2 lists some of those names so that you can understand the different terms you will encounter in a real networking job.

Table 12-2. Different Names for a Leased Line

Name	Meaning or Reference
Leased circuit, circuit	The words *line* and *circuit* are often used as synonyms in telco terminology; circuit makes reference to the electrical circuit between the two endpoints.
Serial link, serial line	The words *link* and *line* are also often used as synonyms. *Serial* in this case refers to the fact that the bits flow serially and that routers use serial interfaces.
point-to-point link, point-to-point line	Refers to the fact that the topology stretches between two points, and 2 points only. (Some older leased lines allowed more than 2 devices.)
T1	A specific type of leased line that transmits data at 1.544 megabits per second (1.544 Mbps).
WAN link, Link	Both these terms are very general, with no reference to any specific technology.

The Physical Components of a Leased Line

To create a leased line, the telco must create some physical transmission path between the two routers on the ends of the link. The physical cabling must leave the buildings where each router sits. Then the telco must create the equivalent of a two-pair circuit from end to end, with one circuit to send data in each direction (full duplex). Figure 12-3 shows one such example, in which the telco uses a couple of traditional central office (CO) switches to create a short leased line between two routers.

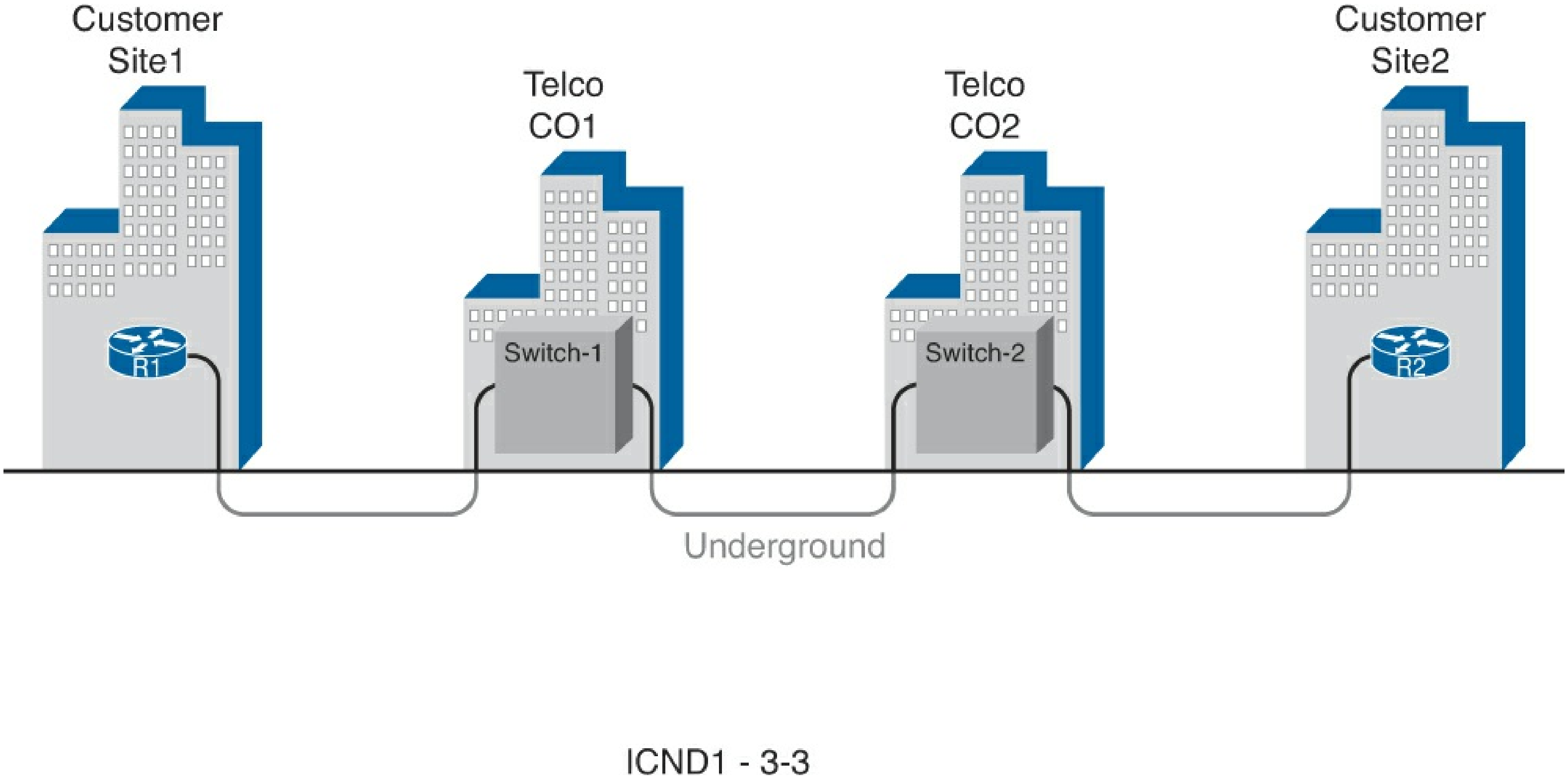


Figure 12-3. Possible Cabling Inside a Telco for a Short Leased Line

The details in the center of Figure 12-3 probably show more than you ever need to know about leased-line WANs, at least from the enterprise customer perspective. More commonly, most network engineers think more about a leased line from the perspective of Figure 12-4, which shows a few key components and terms for the equipment on the ends of a leased line, as follows:

Customer premise equipment (CPE): This telco term refers to the gear that sits at their customer's sites on the ends on the link.

Channel service unit/data service unit (CSU/DSU): This device provides a function called *clocking*, in which it physically controls the speed and timing at which the router serial interface sends and receives each bit over the serial cable.

Serial cable: This is a short cable that connects the CSU and the router serial interface.

Key Topic

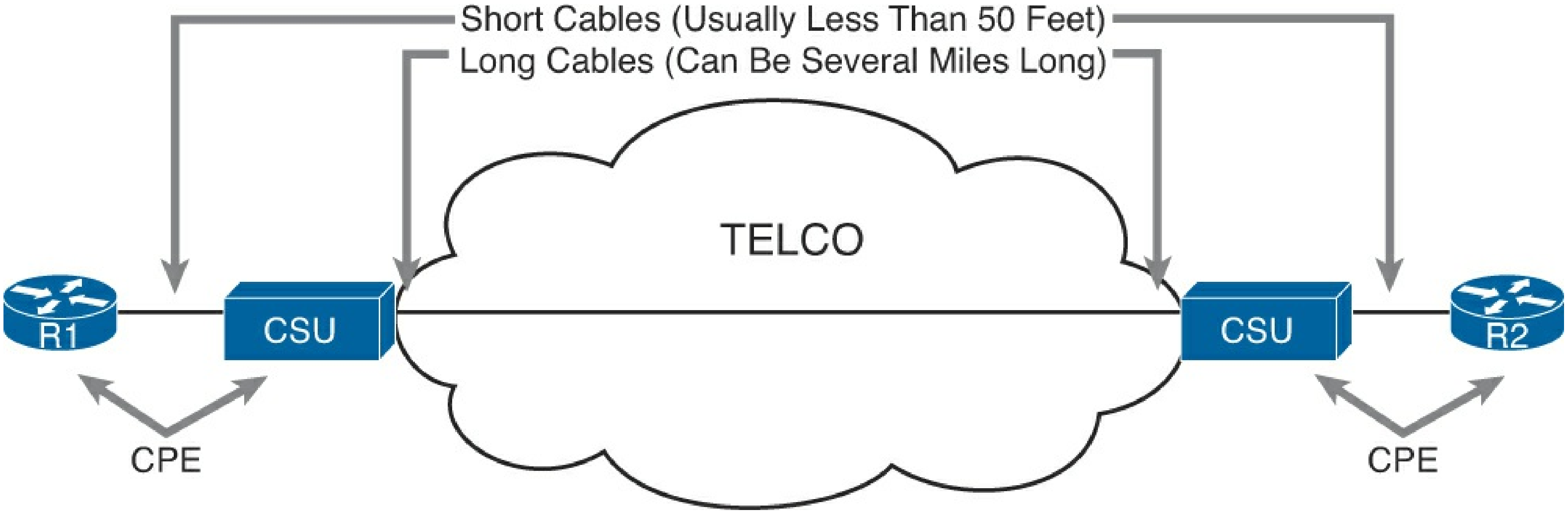

Short Cables (Usually Less Than 50 Feet)
Long Cables (Can Be Several Miles Long)
TELCO
R1
CSU
CSU
R2
CPE
CPE

Figure 12-4. Point-to-Point Leased Line: Components and Terminology

The CPE includes several separately orderable parts. With an external CSU/DSU, a serial cable must be used to connect to the CSU to the router serial interface. Many routers today use serial interfaces. These serial interfaces usually exist as part of a removable card on the router, called WAN interface cards (WIC). The WIC has one style (size/shape) physical connector, whereas the CSU has one of several other types of connectors. So, when installing the leased line, the engineer must choose the correct cable type, with connectors to match the WIC on one end and the CSU/DSU on the other.

Figure 12-5 shows drawings of three types of serial cables. All have a smart serial connector on the top end, which is a commonly used connector on many Cisco serial interface cards. The other end in each cable uses one of the common physical serial connector standards found in CSU/DSU products.

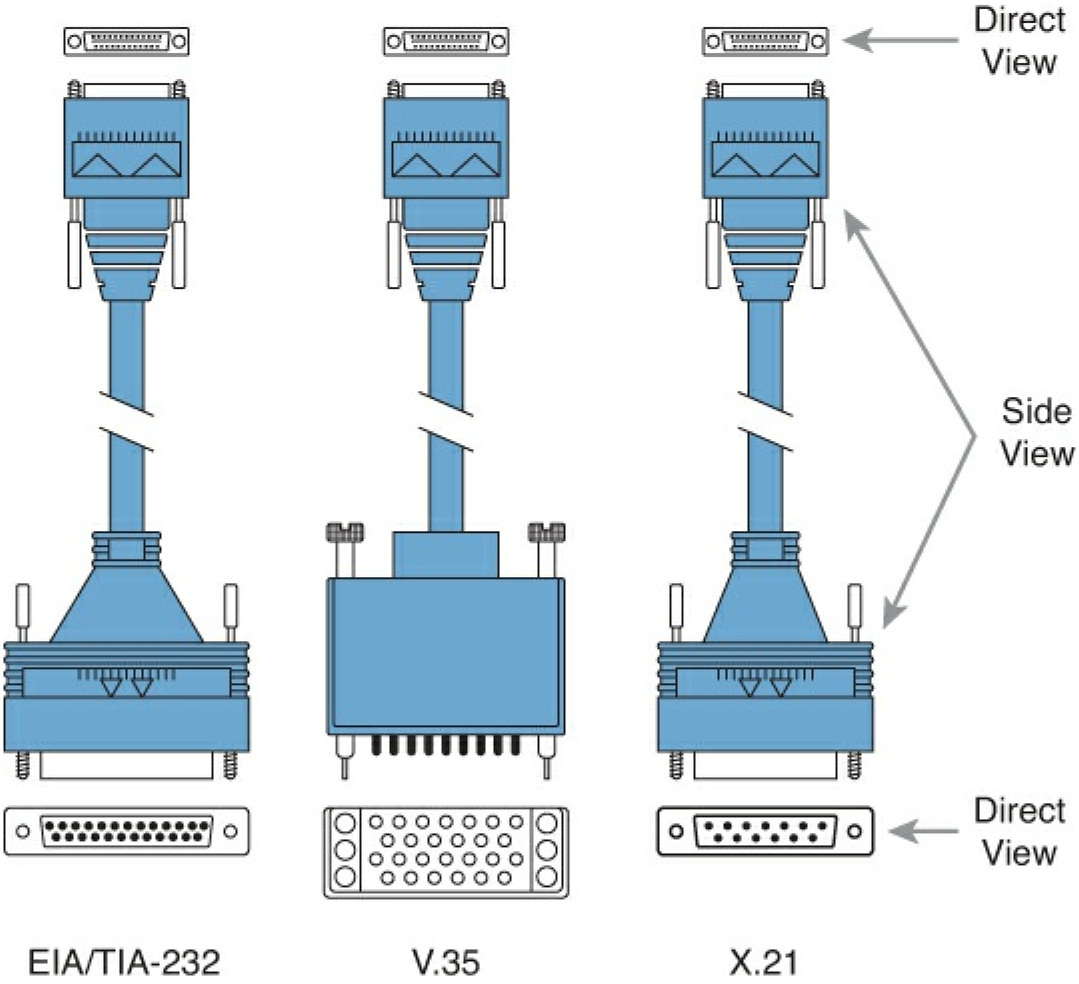


Figure 12-5. Serial Cables Used Between a CSU and a Router

Today, many leased lines make use of Cisco WICs with an integrated CSU/DSU. That is, the WIC hardware includes the same functions as a CSU/DSU, so an external CSU/DSU is not needed. Compared to Figure 12-4, the external CSU/DSU and serial cable on each end are not needed, with the cable from the telco connecting directly to the WIC.

Figure 12-6 shows a photo of a router with four WIC slots. Each slot currently shows a faceplate with no WIC cards installed. The foreground of the figure shows a WIC-4T1/E1, a card that supports four serial links with integrated CSU/DSU. The WIC shows four RJ-48 ports on the front of the card; these connectors have the same size and shape as the familiar RJ-45.

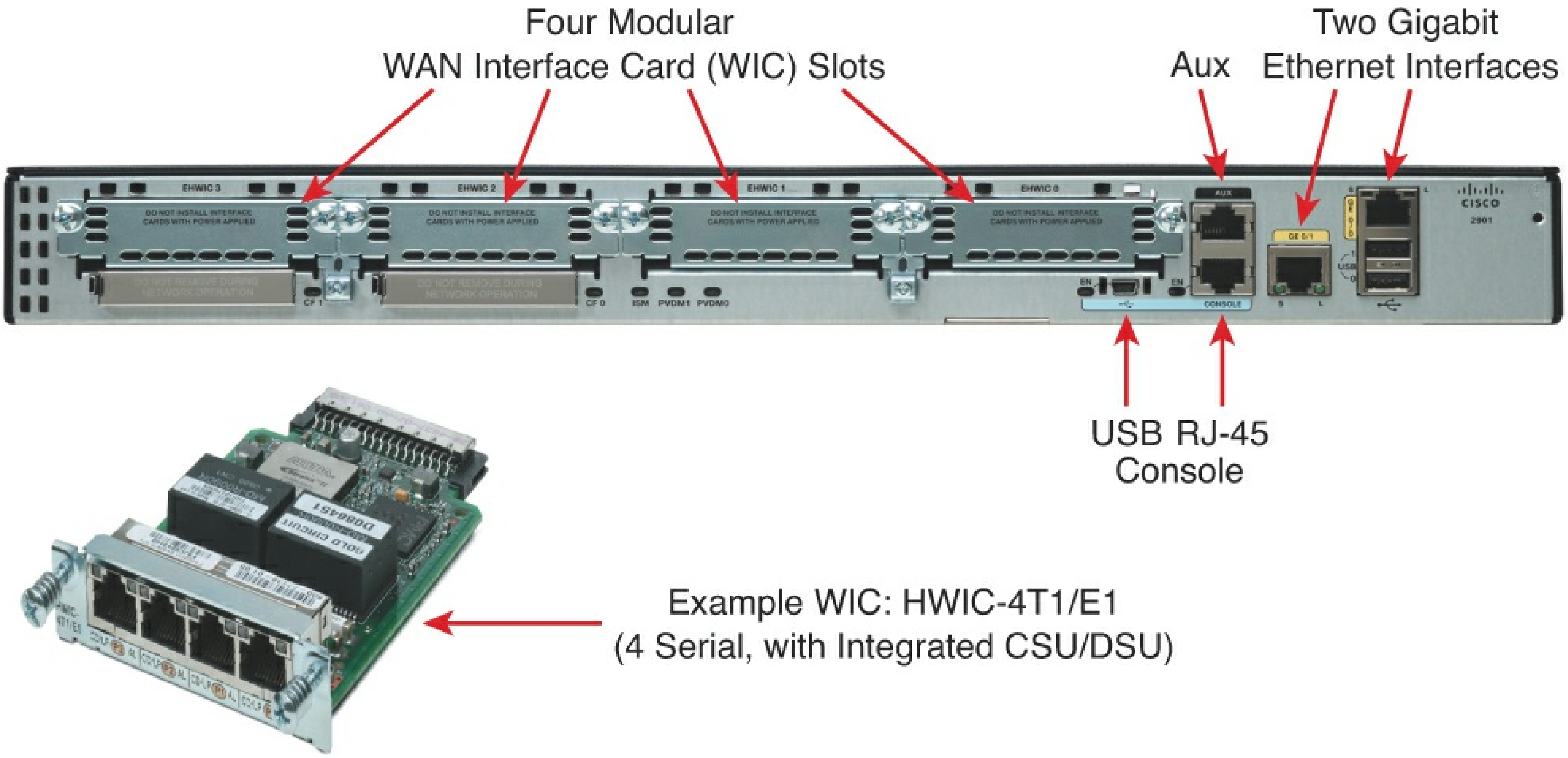


Figure 12-6. Photo of Router with Serial WIC with Integrated CSU/DSU and RJ-48 Ports

Leased Lines and the T-Carrier System

Telcos offer a wide variety of speeds for leased lines. However, a telco customer cannot pick just any speed. Instead, the speeds follow the standards of an age-old technology called the T-carrier system.

Back in the 1950s and 1960s, the U.S.-based Bell companies developed and deployed digital voice and the T-carrier system. As part of that work, they standardized different transmission speeds, including 64 Kbps, 1.544 Mbps, and 44.736 Mbps.

Those same Bell companies developed time-division multiplexing (TDM) technology that let them combine multiple of these base speeds onto a single line. For instance, one popular standard, a Digital Signal level 1 (DS1), or T1, combines 24 DS0s (at 64 Kbps) plus 8 Kbps of overhead into one physical line that runs at 1.544 Mbps. However, to allow flexibility of speeds offered to customers, the telco could install a T1 line to many sites, but run some at slower speeds and some and faster speeds—as long as those speeds were multiples of 64 Kbps.

Now back to the idea of the speed of a leased line. What can you actually buy? Basically, at slower speeds, you get any multiple of 64 Mbps, up to T1 speed. At faster speeds, you can get multiples of T1 speed, up to T3 speed. Table 12-3 summarizes the speeds.

Key Topic

Table 12-3. WAN Speed Summary

Names of Line	Bit Rate
DS0	64 Kbps
Fractional T1	Multiples of 64 Kbps, up to 24X
DS1 (T1)	1.544 Mbps (24 DS0s, for 1.536 Mbps, plus 8 Kbps overhead)
Fractional T3	Multiples of 1.536 Mbps, up to 28X
DS3 (T3)	44.736 Mbps (28 DS1s, plus management overhead)

The Role of the CSU/DSU

For our last bit of discussion about WAN links in a working enterprise internetwork, next consider the role of the CSU/DSU (called CSU for short). For the sake of discussion, the next few paragraphs, leading up to Figure 12-7, assume a leased line with external CSU/DSUs, like earlier in Figure 12-4.

Key Topic

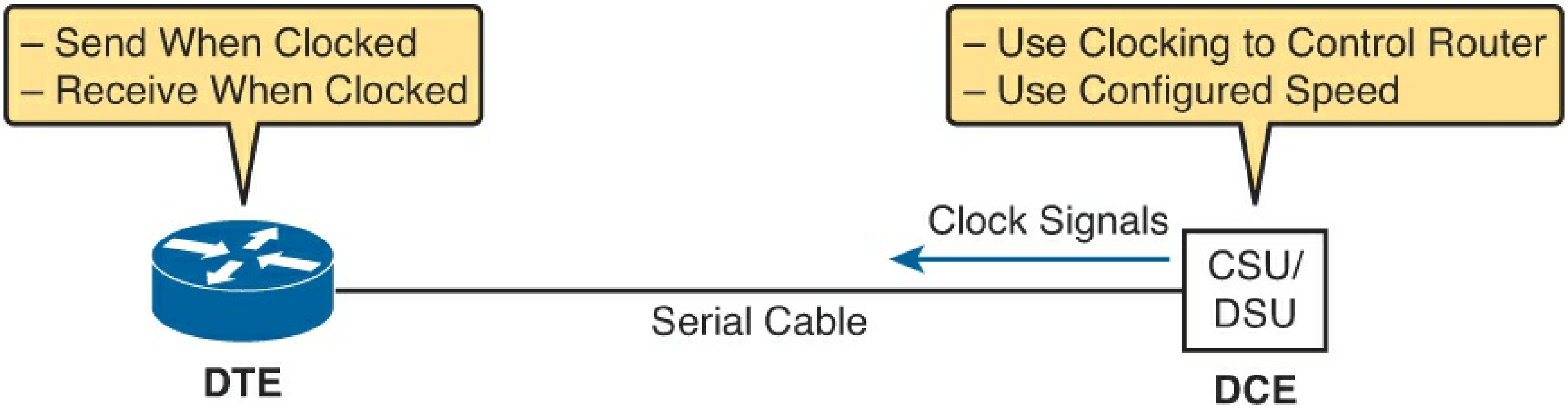


Figure 12-7. DCE and DTE Roles for a CSU/DSU and a Router Serial Interface

> **Note**
>
> Many people refer to a CSU/DSU as simply a CSU.

The CSU sits between the telco leased line and the router; it understands both worlds and their conventions at Layer 1. On the telco side, that means the CSU connects to the line from the telco, so it must understand all these details about the T-carrier system, TDM, and the speed used by the telco. The CSU must be configured to match the telco's settings to run at the same speed. For instance, a CSU connected to a 256-Kbps fractional T1 requires different configuration from one connected to a full T1 (1.544 Mbps).

On the router side of the equation, the CSU connects to the router, with roles called the DCE and DTE, respectively. The CSU, acting as DCE (data circuit-terminating equipment), controls the speed of the router. The router, acting as DTE (data terminal equipment), is controlled by the clocking signals from CSU (DCE). That is, the CSU tells the router when to send and receive bits; the router attempts to send and receive bits only when the DCE creates the correct electrical impulses (called clocking) on the cable.

The DCE and DTE concept works a little like an overanxious child who is ready to throw balls to the parent as fast as possible. But the child must wait until each time his parent shouts "Now!" The parent sits there and shouts "Now! Now! Now! Now!" at a regular pace: the pace at which the parent is willing to catch the balls. Similarly, the CSU/DSU has configuration that tells it the speed at which to clock the router, with the CSU shouting "Now!" by changing the electrical current on some wires (clock signals) in the serial cable.

Figure 12-7 shows a diagram of those main concepts of the role of the CSU/DSU.

Building a WAN Link in a Lab

On a practical note, to prepare for the CCENT and CCNA exams, you might choose to buy some used router and switch hardware for hands-on practice. If you do, you can create the equivalent of a leased line, without a real leased line from a telco and without CSU/DSUs, just using a cabling trick. This short discussion tells you enough information to create a WAN link in your home lab.

First, when building a real WAN link with a real telco facility between sites, the serial cables normally used between a router and an external CSU/DSU are called *DTE cables*. For example, the conceptual drawing in earlier Figure 12-4 would use a DTE serial cable between each router and the CSU.

You can create an equivalent WAN link just by connecting two routers' serial interfaces using one DTE cable and a slightly different DCE cable, with no CSUs and with no leased line from the telco. The DCE cable has a female connector, and the DTE cable has a male connector, which allows the two cables can be attached directly. That completes the physical connection, providing a path for the data. The DCE cable also does the equivalent of an Ethernet crossover cable by swapping the transmit and receive wire pairs, as shown in Figure 12-8.

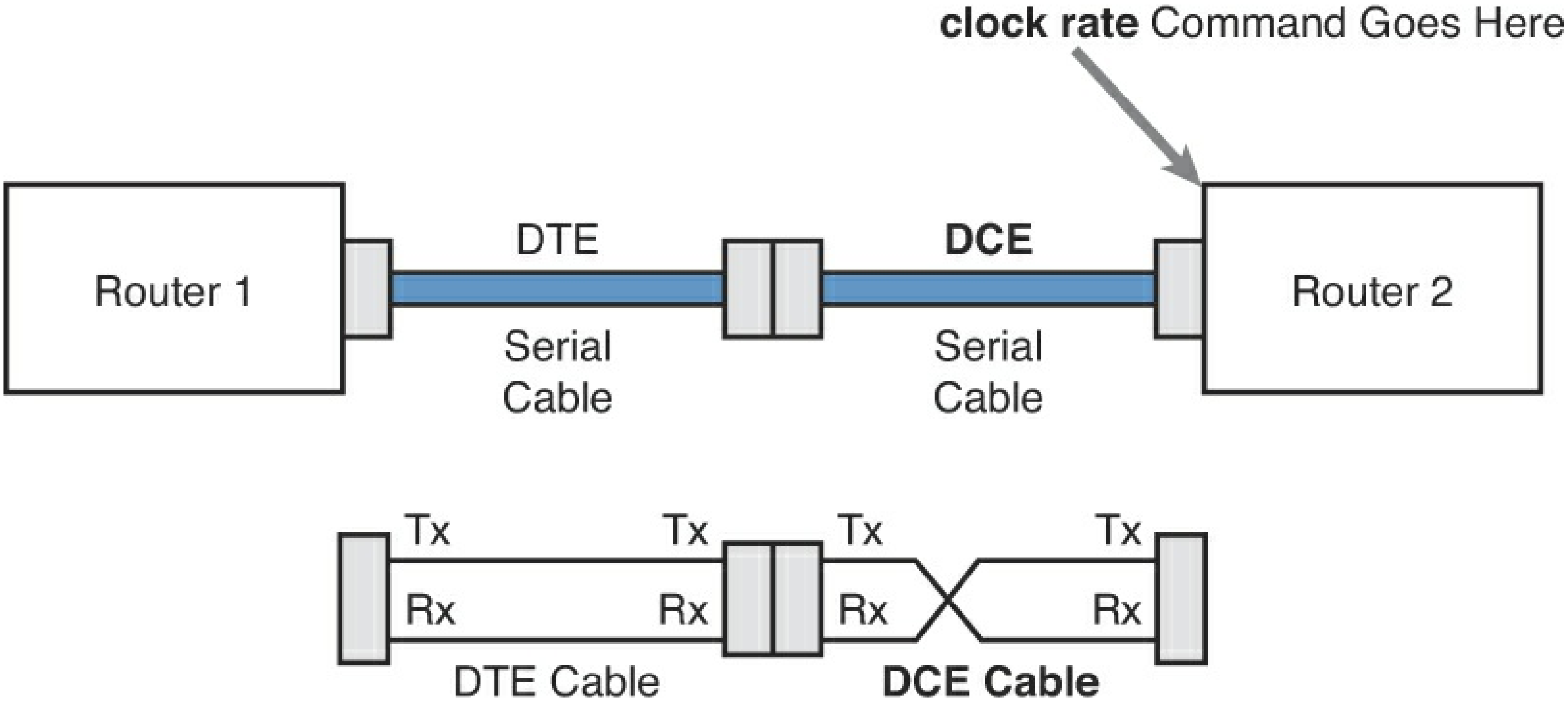


Figure 12-8. Serial Cabling Uses a DTE Cable and a DCE Cable

The figure shows the cable details at the top, with the wiring details at the bottom. In particular, at the bottom of the figure, note that the DTE serial cable acts as a straight-through cable and does not swap the transmit and receive pair, whereas the DCE cable does swap the pairs.

> **Note**
>
> Many vendors, for convenience, sell a single cable that combines the two cables shown in Figure 12-8 into a single cable. Search online for "Cisco serial crossover" to find examples.

Finally, to make the link work, the router with the DCE cable installed must provide clocking. A router serial interface can provide clocking, but it can do so only if a DCE cable is connected to the interface and by the configuration of the **clock rate** command. (Note that the more recent versions of IOS, when the router notices a DCE cable connected to a serial interface, but with no **clock rate** command configured, the router automatically adds a **clock rate** command so that the link can work.)

Layer 2 Leased Lines with HDLC

A leased line provides a Layer 1 service. In other words, it promises to deliver bits between the devices connected to the leased line. However, the leased line itself does not define a data link layer protocol to be used on the leased line. HDLC provides one option for a data link protocol for a leased line.

HDLC has only a few big functions to perform with the simple point-to-point topology of a point-to-point leased line. First, the frame header lets the receiving router know that a new frame is coming. Plus, like all the other data link protocols, the HDLC trailer has a Frame Check Sequence (FCS) field that the receiving router can use to decide whether the frame had errors in transit, and if so, discard the frame.

Cisco adds another function to the ISO standard HDLC protocol by adding an extra field (a Type field) to the HDLC header, creating a Cisco-specific version of HDLC, as shown in Figure 12-9. The Type field allows Cisco routers to support multiple types of network layer packets to cross the HDLC link. (The original HDLC standard, which predated routers by many years, did not have a Type field.) For example, an HDLC link between two Cisco routers can forward both IPv4 and IPv6 packets because the Type field can identify which type of packet is encapsulated inside each HDLC frame.

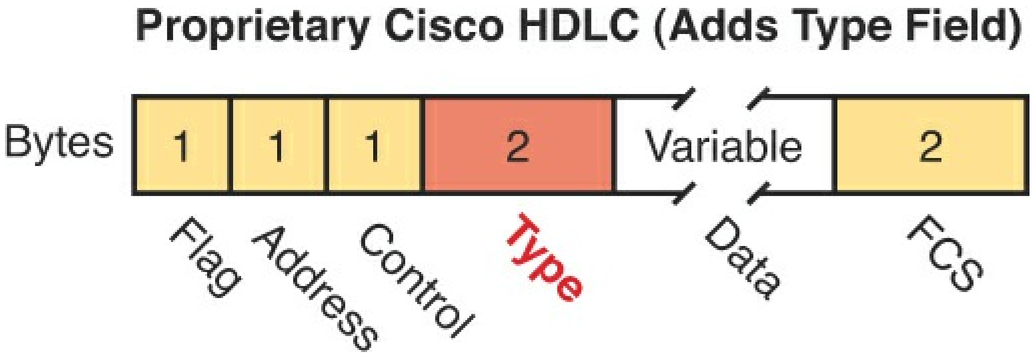


Figure 12-9. Cisco HDLC Framing

Today, the HDLC address and control fields have little work to do. For instance, with only two routers on a link, when a router sends a frame, it is clear that the frame is sent to the only other router on the link. Both the Address and Control fields had important purposes in years past, but today they are unimportant.

Note

In case you wonder why HDLC has an Address field at all, in years past the telcos offered multidrop circuits. These circuits included more than two devices, so there was more than one possible destination, requiring an Address field to identify the correct destination.

Routers often use HDLC as the data link protocol on a leased line, as shown in Figure 12-10. Routers use HDLC just like any other data link protocol used by routers: to move packets to the next router. Figure 12-10 shows three familiar routing steps, with the role of HDLC sitting at Step 2. (Note that the figure does not show the data link trailer with each frame.)

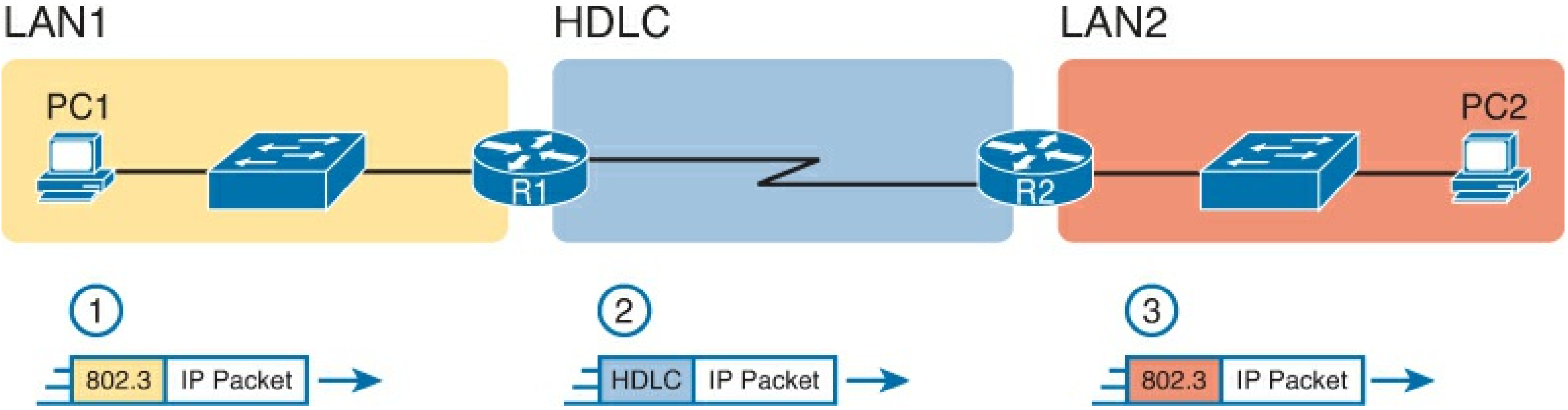


Figure 12-10. General Concept of Routers Deencapsulating and Reencapsulating IP Packets

Here is a walkthrough of the steps in the figure:

1. To send the IP packet to router R1, PC1 encapsulates the IP packet in an Ethernet frame.
2. Router R1 deencapsulates (removes) the IP packet, encapsulates the packet into a HDLC frame using an HDLC header and trailer, and forwards the HDLC frame to router R2.
3. Router R2 deencapsulates (removes) the IP packet, encapsulates the packet into an Ethernet frame, and forwards the Ethernet frame to PC2.

In summary, a leased line with HDLC creates a WAN link between two routers so that they can forward packets for the devices on the attached LANs. The leased line itself provides the physical means to transmit the bits, in both directions. The HDLC frames provide the means to encapsulate the network layer packet correctly so it crosses the link between routers.

Configuring HDLC

Think back to router LAN interfaces for a moment. Routers require no configuration related to Layers 1 and 2 for the interface to be up and working, forwarding IP traffic. The Layer 1 details occur by default once the cabling has been installed correctly. Router Ethernet interfaces of course use Ethernet as the data link protocol by default. The router only needs to configure an IP address on the interface, and possibly enable the interface with the **no shutdown** command if the interface is in an "administratively down" state.

Similarly, serial interfaces on Cisco routers need no specific Layer 1 or 2 configuration commands. For Layer 1, the cabling needs to be completed, of course, but the router attempts to use the serial interface once the **no shutdown** command is configured. For Layer 2, IOS defaults to use HDLC on serial interfaces. As on Ethernet interfaces, router serial interfaces usually only need an **ip address** command, and possibly the **no shutdown** command.

However, many optional commands exist for serial links. The following list outlines some configuration steps, listing the conditions for which some commands are needed, plus commands that are purely optional:

Key Topic

Step 1. Configure the interface IP address using the **ip address** interface subcommand.

Step 2. The following tasks are required only when the specifically listed conditions are true:

- **A.** If an **encapsulation** *protocol* interface subcommand already exists, for a non-HDLC protocol, enable HDLC using the **encapsulation hdlc** interface subcommand. Alternatively, make the interface revert back to its default encapsulation by using the **no encapsulation** *protocol* interface subcommand to disable the currently enabled protocol.
- **B.** If the interface line status is administratively down, enable the interface using the **no shutdown** interface subcommand.
- **C.** If the serial link is a back-to-back serial link in a lab (or a simulator), configure the clocking rate using the **clock rate** *speed* interface subcommand, but only on the one router with the DCE cable (per the **show controllers serial** *number* command).

Step 3. The following steps are always optional and have no impact on whether the link works and passes IP traffic:

- **A.** Configure the link's speed using the **bandwidth** *speed-in-kbps* interface subcommand to match the actual speed of the link.
- **B.** For documentation purposes, configure a description of the purpose of the interface using the **description** *text*

interface subcommand.

In practice, when you configure a Cisco router with no preexisting interface configuration and install a normal production serial link with CSU/DSUs, the **ip address** and **no shutdown** commands are likely the one configuration commands you would need.

Figure 12-11 shows a sample internetwork, and Example 12-1 shows the matching HDLC configuration. In this case, the serial link was created with a back-to-back serial link in a lab, requiring Steps 1 (**ip address**) and 2C (**clock rate**) from the preceding list. It also shows optional Step 3B (**description**).

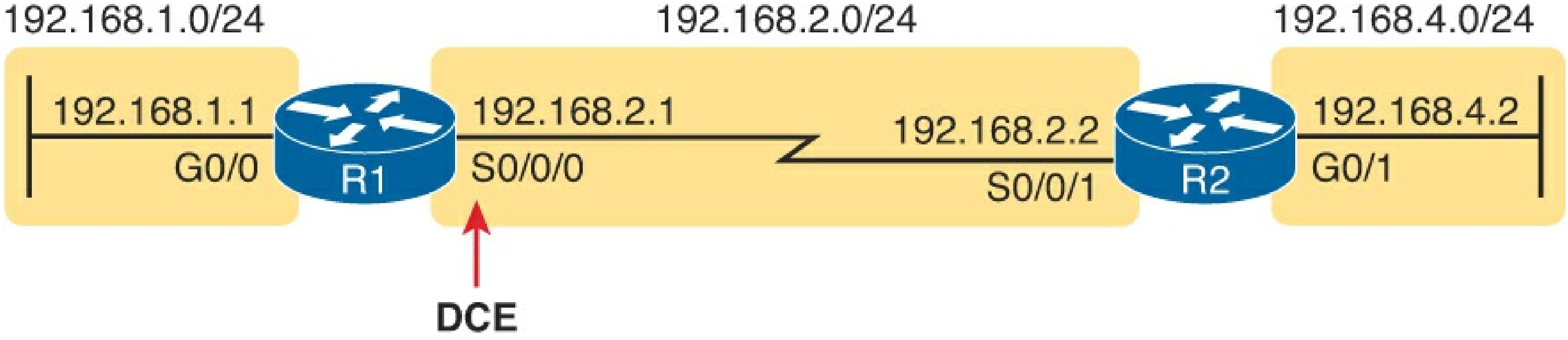


Figure 12-11. Typical Serial Link Between Two Routers

Example 12-1. HDLC Configuration

Click here to view code image

```
R1# show running-config
! Note - only the related lines are shown
interface GigabitEthernet0/0
ip address 192.168.1.1 255.255.255.0
!
interface Serial0/0/0
ip address 192.168.2.1 255.255.255.0
description link to R2
clock rate 2000000
!
router eigrp 1
network 192.168.1.0
network 192.168.2.0
```

The configuration on R1 is relatively simple. The matching configuration on R2’s S0/0/1 interface simply needs an **ip address** command plus the default settings of **encapsulation hdlc** and **no shutdown**. The **clock rate** command would not be needed on R2 because R1 has the DCE cable, so R2 must be connected to a DTE cable.

Example 12-2 lists two commands that confirm the configuration on R1 and some other default settings. First, it lists the output from the **show controllers** command for S0/0/0, which confirms that R1 indeed has a DCE cable installed and that the clock rate has been set to 2000000 bps. The **show interfaces S0/0/0** command lists the various configuration settings near the top, including the default encapsulation value (HDLC) and default bandwidth setting on a serial interface (1544, meaning 1544 Kbps or 1.544 Mbps). It also lists the IP address, prefix-style mask (/24), and description, as configured in Example 12-1.

Example 12-2. Verifying the Configuration Settings on R1

Click here to view code image

```
R1# show controllers serial 0/0/0
Interface Serial0/0/0
Hardware is SCC
DCE V.35, clock rate 2000000
! lines omitted for brevity

R1# show interfaces s0/0/0
Serial0/0/0 is up, line protocol is up
Hardware is WIC MBRD Serial
Description: link to R2
Internet address is 192.168.2.1/24
MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
reliability 255/255, txload 1/255, rxload 1/255
Encapsulation HDLC, loopback not set
Keepalive set (10 sec)
Last input 00:00:01, output 00:00:00, output hang never
Last clearing of "show interface" counters never
Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
Queueing strategy: fifo
Output queue: 0/40 (size/max)
5 minute input rate 0 bits/sec, 0 packets/sec
5 minute output rate 0 bits/sec, 0 packets/sec
276 packets input, 19885 bytes, 0 no buffer
Received 96 broadcasts (0 IP multicasts)
0 runts, 0 giants, 0 throttles
0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored, 0 abort
284 packets output, 19290 bytes, 0 underruns
0 output errors, 0 collisions, 5 interface resets
0 unknown protocol drops
0 output buffer failures, 0 output buffers swapped out
7 carrier transitions
DCD=up DSR=up DTR=up RTS=up CTS=up
```

Finally, the router uses the serial interface only if it reaches an up/up interfaces status, as shown in the first line of the output of the **show interfaces S0/0/0** command in Example 12-2. Generally speaking, the first status word refers to Layer 1 status, and the second refers to Layer 2 status. For a quicker look at the interface status, instead use either the **show ip interface brief** and **show interfaces description** commands, as listed in Example 12-3.

Example 12-3. Brief Lists of Interfaces and Interface Status

Click here to view code image

```
R1# show ip interface brief
Interface IP-Address OK? Method Status Protocol
GigabitEthernet0/0 192.168.1.1 YES manual up up
GigabitEthernet0/1 unassigned YES manual administratively down down
Serial0/0/0 192.168.2.1 YES manual up up
Serial0/0/1 unassigned YES NVRAM administratively down down
Serial0/1/0 unassigned YES NVRAM administratively down down
Serial0/1/1 unassigned YES NVRAM administratively down down

R1# show interfaces description
Interface Status Protocol Description
Gi0/0 up up LAN at Site 1
Gi0/1 admin down down
Se0/0/0 up up link to R2
Se0/0/1 admin down down
Se0/1/0 admin down down
Se0/1/1 admin down down
```

Leased-Line WANs with PPP

Point-to-Point Protocol (PPP) plays the same role as HDLC: a data link protocol for use on serial links. However, HDLC was created for a world without routers. In contrast, PPP, defined in the 1990s, was designed with routers, TCP/IP, and other network layer protocols in mind, with many more advanced features.

This second major section of this chapter first discusses PPP concepts, including one example of a more advanced PPP feature (authentication). This section ends with some configuration examples using PPP.

PPP Concepts

PPP provides several basic but important functions that are useful on a leased line that connects two devices:

Key Topic

- Definition of a header and trailer that allows delivery of a data frame over the link
- Support for both synchronous and asynchronous links
- A protocol Type field in the header, allowing multiple Layer 3 protocols to pass over the same link
- Built-in authentication tools: Password Authentication Protocol (PAP) and Challenge Handshake Authentication Protocol (CHAP)
- Control protocols for each higher-layer protocol that rides over PPP, allowing easier integration and support of those

protocols

The next several pages take a closer look at the protocol field, authentication, and the control protocols.

PPP Framing

Unlike the standard version of HDLC, the PPP standard defines a protocol field. The protocol field identifies the type of packet inside the frame. When PPP was created, this field allowed packets from the many different Layer 3 protocols to pass over a single link. Today, the protocol Type field still provides the same function, usually supporting packets for the two different versions of IP (IPv4 and IPv6). Figure 12-12 shows the PPP framing, which happens to mirror the Cisco proprietary HDLC framing that includes a protocol Type field (as shown earlier in Figure 12-9).

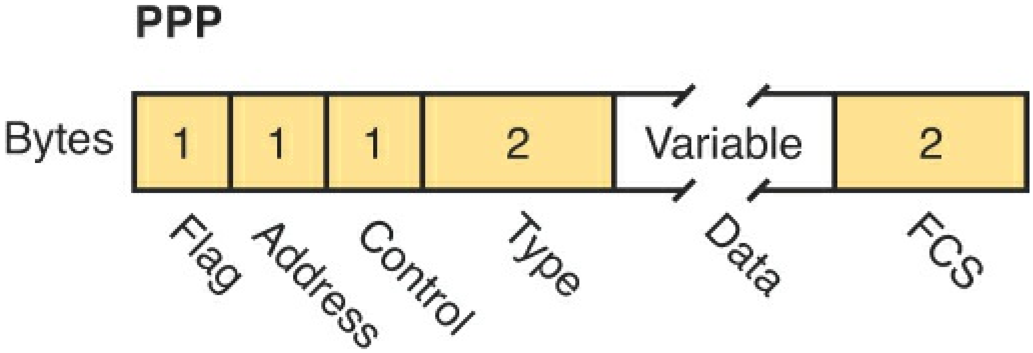


Figure 12-12. PPP Framing

PPP Control Protocols

In addition to HDLC-like framing, PPP defines a set of Layer 2 control protocols that perform various link control functions. The idea of these extra protocols works a little like how Ethernet includes additional protocols like Spanning Tree Protocol (STP). Ethernet has headers and trailers to deliver frames, plus it defines overhead protocols like STP to help make the frame forwarding process work better. Likewise, PPP defines the frame format in Figure 12-12, plus it defines other protocols to help manage and control the serial link.

PPP separates these control protocols into two main categories:

- **Link Control Protocol (LCP):** This one protocol has several different individual functions, each focused on the data link itself, ignoring the Layer 3 protocol sent across the link.
- **Network Control Protocols (NCP):** This is a category of protocols, one per network layer protocol. Each protocol does functions specific to its related Layer 3 protocol.

The PPP LCP implements the control functions that work the same regardless of the Layer 3 protocol. For features related to any higher-layer protocols, usually Layer 3 protocols, PPP uses a series of PPP *control protocols* (CP), such as IP Control Protocol (IPCP). PPP uses one instance of LCP per link and one NCP for each Layer 3 protocol defined on the link. For example, on a PPP link using IPv4, IPv6, and Cisco Discovery Protocol (CDP), the link uses one instance of LCP plus IPCP (for IPv4), IPv6CP (for IPv6), and CDPCP (for CDP).

Table 12-4 summarizes the functions of LCP, gives the LCP feature names, and describes the features briefly. Following the table, the text explains one of the features, PPP authentication, in more detail.

Table 12-4. PPP LCP Features

Function	LCP Feature	Description
Looped link detection	Magic number	Detects whether the link is looped, and disables the interface, allowing rerouting over a working route
Error detection	Link-quality monitoring (LQM)	Disables an interface that exceeds an error percentage threshold, allowing rerouting over better routes
Multilink support	Multilink PPP	Load balances traffic over multiple parallel links
Authentication	PAP and CHAP	Exchanges names and passwords so that each device can verify the identity of the device on the other end of the link

PPP Authentication

In networking, *authentication* gives one device a way to confirm that another device is truly the correct and approved device with which communications should occur. In other words, authentication confirms that the other party is the authentic other party, and not some imposter.

For instance, with PPP, if R1 and R2 are supposed to be communicating over a serial link, R1 might want R2 to somehow prove that the device claiming to be R2 really is R2. In that scenario, R1 wants to authenticate R2, with the authentication process providing a way for R2 to prove its identity.

WAN authentication is most often needed when dial lines are used. However, the configuration of the authentication features remains the same whether a leased line or dial line is used.

PPP defines two authentication protocols: PAP and CHAP. Both protocols require the exchange of messages between devices, but with different details. With PAP, the process works with the to-be-authenticated device starting the messages, claiming to be legitimate by listing a secret password in clear text, as shown in Figure 12-13.

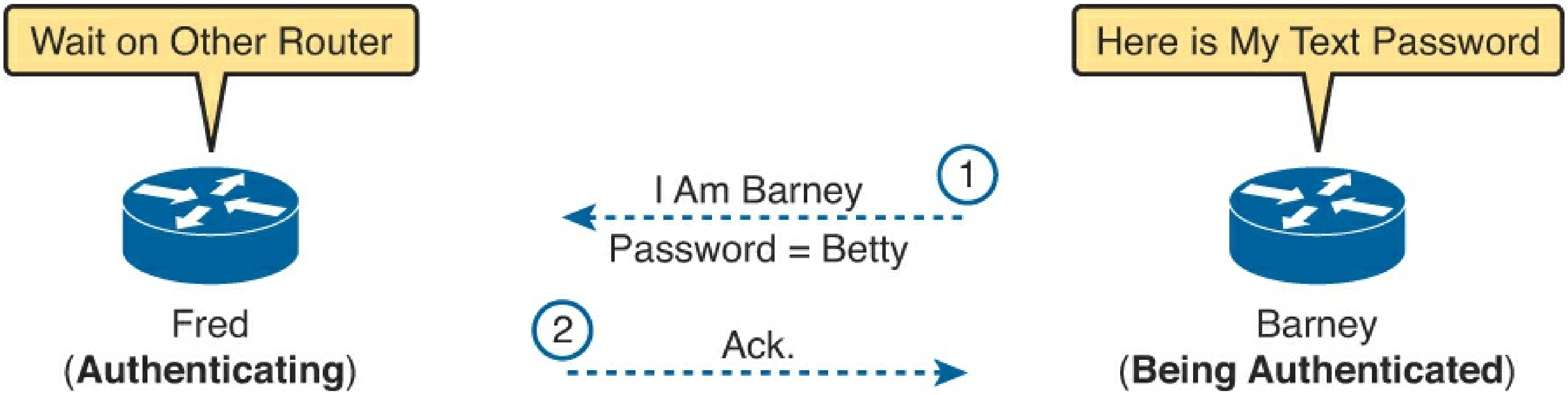


Figure 12-13. PAP Authentication Process

In the figure, when the link comes up, authentication takes two steps. At Step 1, Barney sends the shared password in clear text. Fred, who wants to authenticate Barney—that is, confirm that Barney is the real Barney—sees the password, confirms that it is the correct password, and sends back an acknowledgment that Barney has passed the authentication process.

CHAP, a much more secure option, uses different messages, and it hides the password. With CHAP, the device doing the authentication (Fred) begins with a message called a *challenge*, which asks the other device to reply. The big difference is that the second message in the flow (as shown in Figure 12-14) hides the authentication password by instead sending a hashed version of the password. If Fred confirms that the hashed password is indeed the correct password, Fred sends back a third message to confirm the successful authentication of Barney.

Key Topic

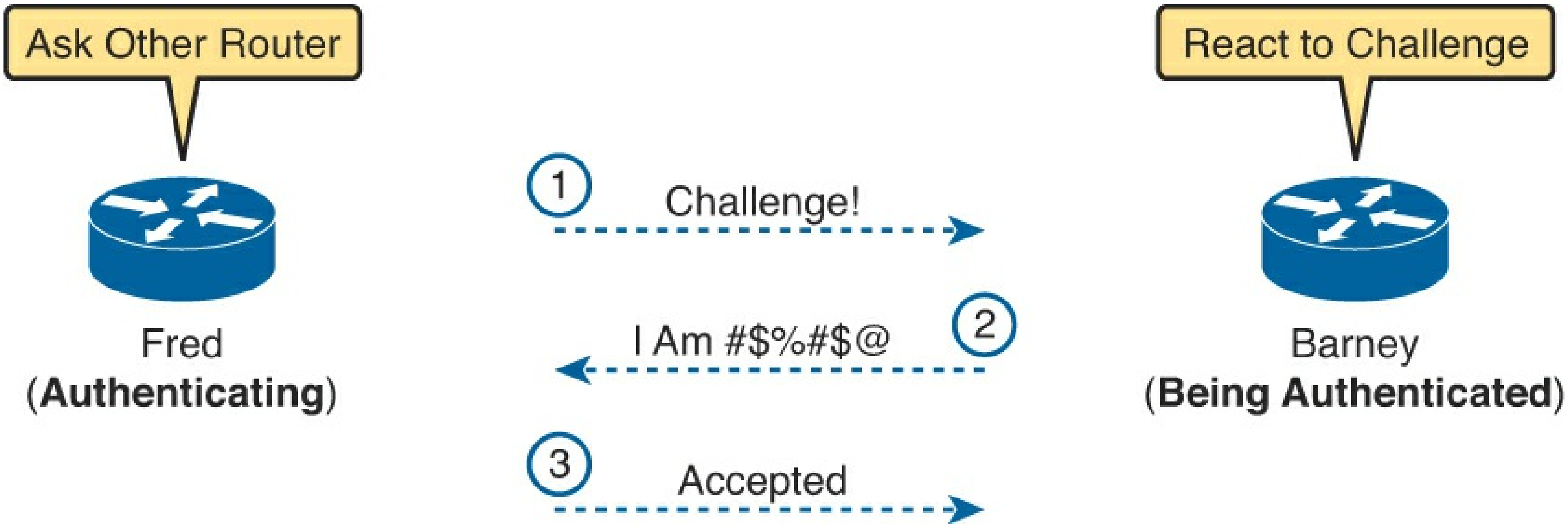


Figure 12-14. CHAP Authentication Process

Both Figure 12-13 and 12-14 show authentication flows when authentication works. When it fails (for instance, if the passwords do not match), a different final message flows. Also, if the authentication fails, PPP leaves the interface in an up/down state, and the router cannot forward and receive frames on the interface.

PAP flows are much less secure than CHAP because PAP sends the hostname and password in clear text in the message. These can be read easily if someone places a tracing tool in the circuit. CHAP instead uses a one-way hash algorithm, called message digest 5 (MD5), with input to the algorithm being a password that never crosses the link plus a shared random number.

The CHAP process also uses a hash value only one time so that an attacker cannot just make a copy of the hashed value and send it at a later date. To make that work, the CHAP challenge (the first CHAP message) states a random number. The challenged router runs the hash algorithm using the just-learned random number and the secret password, and sends the results back to the router that sent the challenge. The router that sent the challenge runs the same algorithm using the random number (sent across the link) and the password (as stored locally); if the results match, the passwords must match.

Later, the next time the authentication process work occurs, the authenticating router generates and uses a different random number.

PAP and CHAP are a few examples of the work done by PPP's LCP. The next topic looks at how to configure and verify PPP.

Configuring PPP

Configuring PPP, as compared to HDLC, requires only one change: using the **encapsulation ppp** command on both ends of the link. As with HDLC, other items can be optionally configured, such as the interface **bandwidth**, and a **description** of the interface. And of course, the interface must be enabled (**no shutdown**). But the configuration to migrate from HDLC to PPP just requires the **encapsulation ppp** command on both routers' serial interfaces.

Example 12-4 shows a simple configuration using the two routers shown in Figure 12-11, the same internetwork used for the HDLC example. The example includes the IP address configuration, but the IP addresses do not have to be configured for PPP to work.

Example 12-4. Basic PPP Configuration

Click here to view code image

```
! The example starts with router R1
interface Serial0/0/0
ip address 192.168.2.1 255.255.255.0
encapsulation ppp
clockrate 2000000
```

```
! Next, the configuration on router R2
interface Serial0/0/1
ip address 192.168.2.2 255.255.255.0
encapsulation ppp
```

The one **show** command that lists PPP details is the **show interfaces** command, with an example from R1 listed in Example 12-5. The output looks just like it does for HDLC up until the first highlighted line in the example. The two highlighted lines confirm the configuration ("Encapsulation PPP"). These lines also confirm that LCP has completed its work successfully, as noted with the "LCP Open" phrase. Finally, the output lists the fact that two CPs, CDPCP and IPCP, have also successfully been enabled—all good indications that PPP is working properly.

Example 12-5. Finding PPP, LCP, and NCP Status with show interfaces

Click here to view code image

```
R1# show interfaces serial 0/0/0
Serial0/0/0 is up, line protocol is up
Hardware is WIC MBRD Serial
Description: link to R2
Internet address is 192.168.2.1/24
MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
reliability 255/255, txload 1/255, rxload 1/255
Encapsulation PPP, LCP Open
Open: IPCP, CDPCP, loopback not set
! Lines omitted for brevity
```

CHAP Configuration and Verification

The simplest version of CHAP configuration requires only a few commands. The configuration uses a password configured on each router. (As an alternative, the password could be configured on an external authentication, authorization, and accounting [AAA] server outside the router.)

To migrate from a configuration that only uses PPP, to a configuration that adds CHAP authentication, follow these steps:

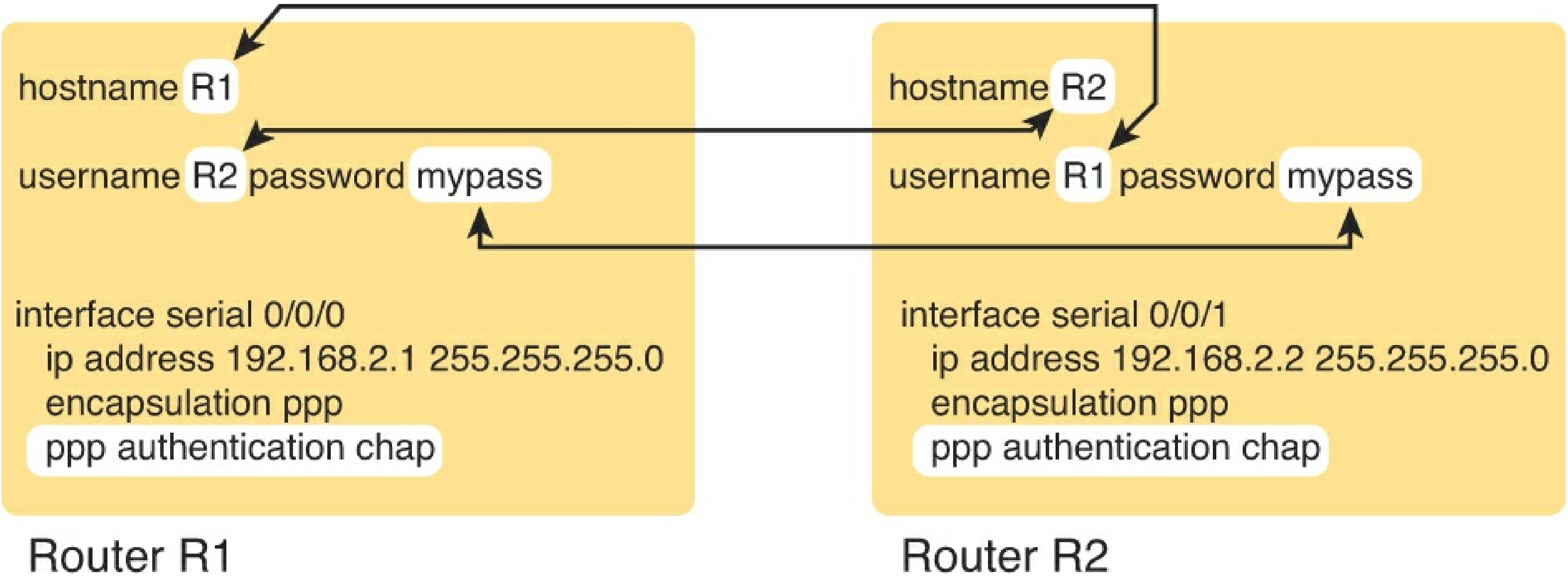
Key Topic

Step 1. Configure the routers' hostnames using the **hostname** *name* global configuration command.

Step 2. Configure the username for the other router, and the shared secret password, using the **username** *name* **password** *password* global configuration command or the **username** *name* secret password command.

Step 3. Enable CHAP on the interface on each router using the **ppp authentication chap** interface subcommand.

Figure 12-15 shows the configuration on both R1 and R2 to both enable PPP and add CHAP to the link. The figure shows how the name in the **hostname** command on one router must match the **username** command on the other router. It also shows that the password defined in each **username** command must be the same (mypass in this case).



```
hostname R1

username R2 password mypass

interface serial 0/0/0
  ip address 192.168.2.1 255.255.255.0
  encapsulation ppp
  ppp authentication chap
```

```
hostname R2

username R1 password mypass

interface serial 0/0/1
  ip address 192.168.2.2 255.255.255.0
  encapsulation ppp
  ppp authentication chap
```

Figure 12-15. CHAP Configuration

Because CHAP is a function of LCP, if the authentication process fails, LCP does not complete and the interface falls to an up and down interface state.

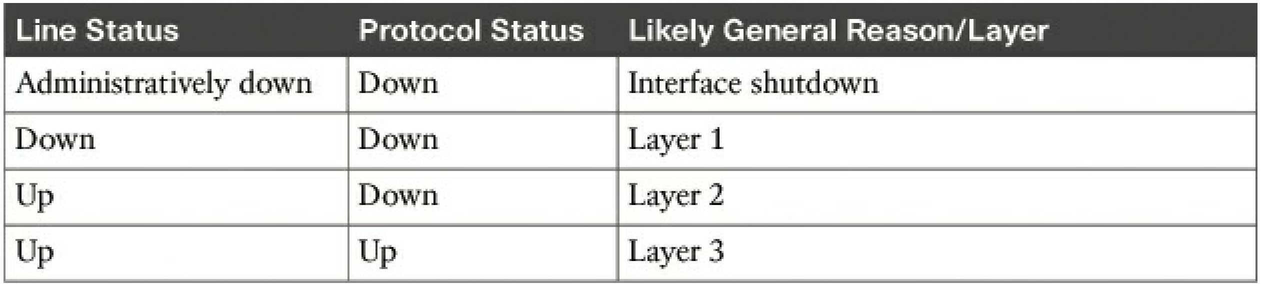
Troubleshooting Serial Links

This final major section discusses how to isolate and find the root cause of problems related to topics covered earlier in this chapter. Also, this section does not attempt to repeat the IP troubleshooting coverage in Parts II and III of this book, but it does point out some of the possible symptoms on a serial link when a Layer 3 subnet mismatch occurs on opposite ends of a serial link, which prevents the routers from routing packets over the serial link.

A simple **ping** command can determine whether a serial link can or cannot forward IP packets. A ping of the other router's serial IP address—for example, a working **ping 192.168.2.2** command on R1 in Figure 12-11, the figure used for both the HDLC and PPP configuration examples—proves that the link either works or does not.

If the **ping** does not work, the problem could be related to functions at Layers 1, 2, or 3. The best way to isolate which layer is the most likely cause is to examine the interface status codes described in Table 12-5.

Table 12-5. Interface Status Codes and Typical Meanings When a Ping Does Not Work



Line Status	Protocol Status	Likely General Reason/Layer
Administratively down	Down	Interface shutdown
Down	Down	Layer 1
Up	Down	Layer 2
Up	Up	Layer 3

The serial link verification and troubleshooting process should begin with a simple three-step process:

Step 1. From one router, ping the other router's serial IP address.

Step 2. If the ping fails, examine the interface status on both routers and investigate problems related to the likely problem areas listed in Table 12-5.

Step 3. If the ping works, also verify that any routing protocols are exchanging routes over the link, as discussed in Chapter 11, "Troubleshooting IPv4 Routing Protocols."

> **Note**
>
> The interface status codes can be found using the **show interfaces**, **show ip interface brief**, and **show interfaces description** commands.

The rest of this section explores the specific items to be examined when the ping fails, based on the combinations of interface status codes listed in Table 12-5.

Troubleshooting Layer 1 Problems

The interface status codes, or interface state, play a key role in isolating the root cause of problems on serial links. In fact, the status on both ends of the link may differ, so it is important to examine the status on both ends of the link to help determine the problem.

For example, a serial link fails when just one of the two routers has administratively disabled its serial interface with the **shutdown** interface subcommand. When one router shuts down its serial interface, the other router sits in a down/down state (line status down, line protocol status down), assuming the second router is not also shutdown. The solution is to just configure a **no shutdown** interface configuration command on the interface.

A serial interface with a *down* line status on both ends of the serial link—that is, both ends in a down/down state—usually points to some Layer 1 problem. Figure 12-16 summarizes the most common causes of this state. In the figure, R2's serial interface has no problems at all; the center and left side of the figure show common root causes that then result in R2's serial interface being in a down/down state.

Key Topic

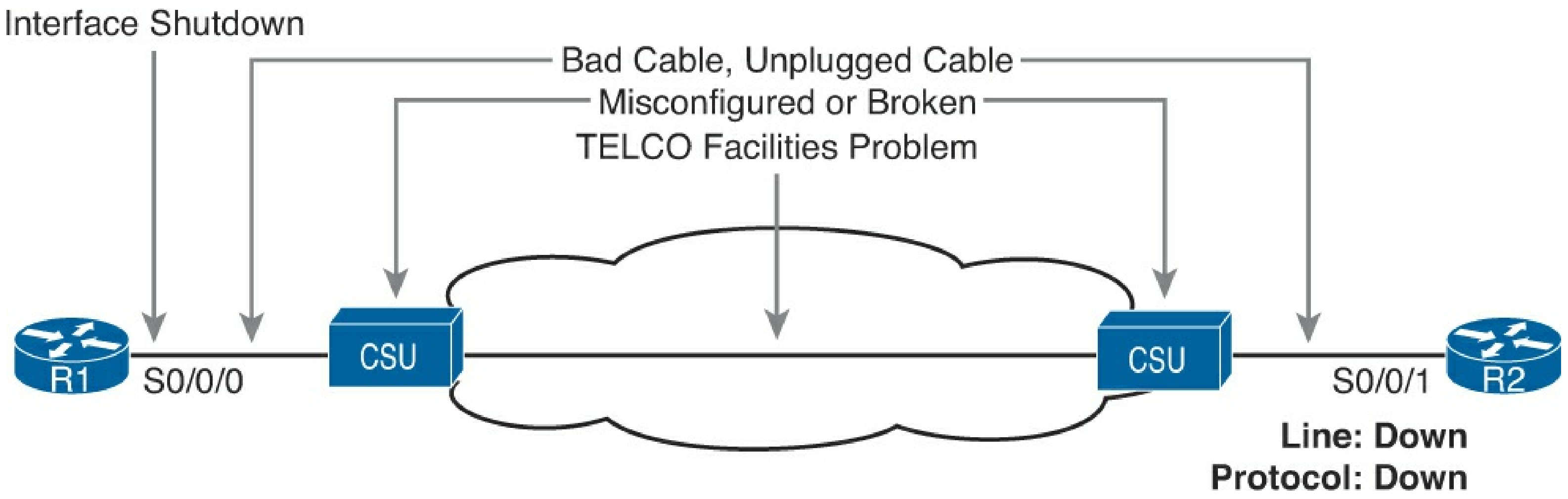


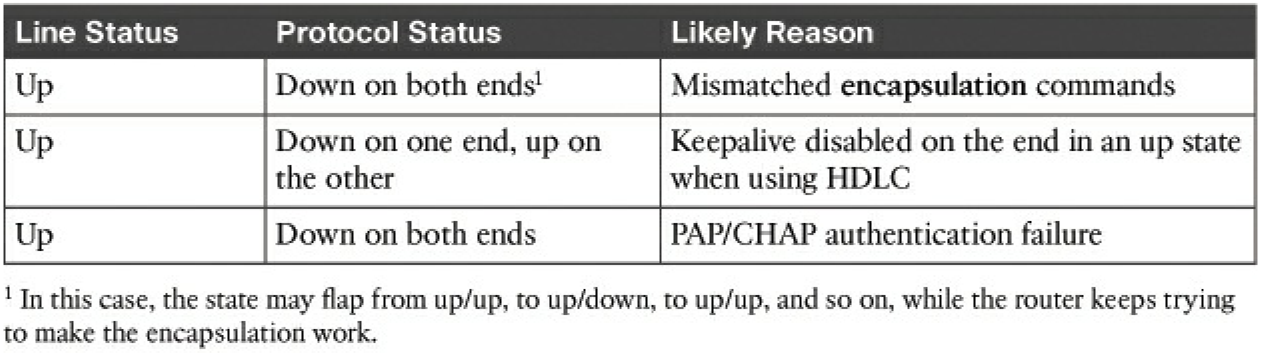
Figure 12-16. Problems That Result in a Down/Down State on Router R2

Troubleshooting Layer 2 Problems

Data link layer problems on serial links usually result in at least one of the routers having a serial interface status of up/down. In other words, the line status (the first status code) is up, while the second status (the line protocol status) is down. Table 12-6 summarizes these types of problems.

Key Topic

Table 12-6. Likely Reasons for Data Link Problems on Serial Links



Line Status	Protocol Status	Likely Reason
Up	Down on both ends[1]	Mismatched **encapsulation** commands
Up	Down on one end, up on the other	Keepalive disabled on the end in an up state when using HDLC
Up	Down on both ends	PAP/CHAP authentication failure

[1] In this case, the state may flap from up/up, to up/down, to up/up, and so on, while the router keeps trying to make the encapsulation work.

Note

As with the other troubleshooting topics in this book, Table 12-6 lists some of the more common types of failures but not all.

The first of these problems—a mismatch between the configured data link protocols—is easy to identify and fix. The **show interfaces** command lists the encapsulation type on about the seventh line of the output, so using this command on both routers can quickly identify the problem. Alternatively, a quick look at the configuration, plus remembering that HDLC is the default serial encapsulation, can confirm whether the encapsulations are mismatched. The solution is simple: Reconfigure one of the two routers to match the other router's **encapsulation** command.

The other two root causes require a little more discussion to understand the issue and determine if they are the real root cause. The next two headings take a closer look at each.

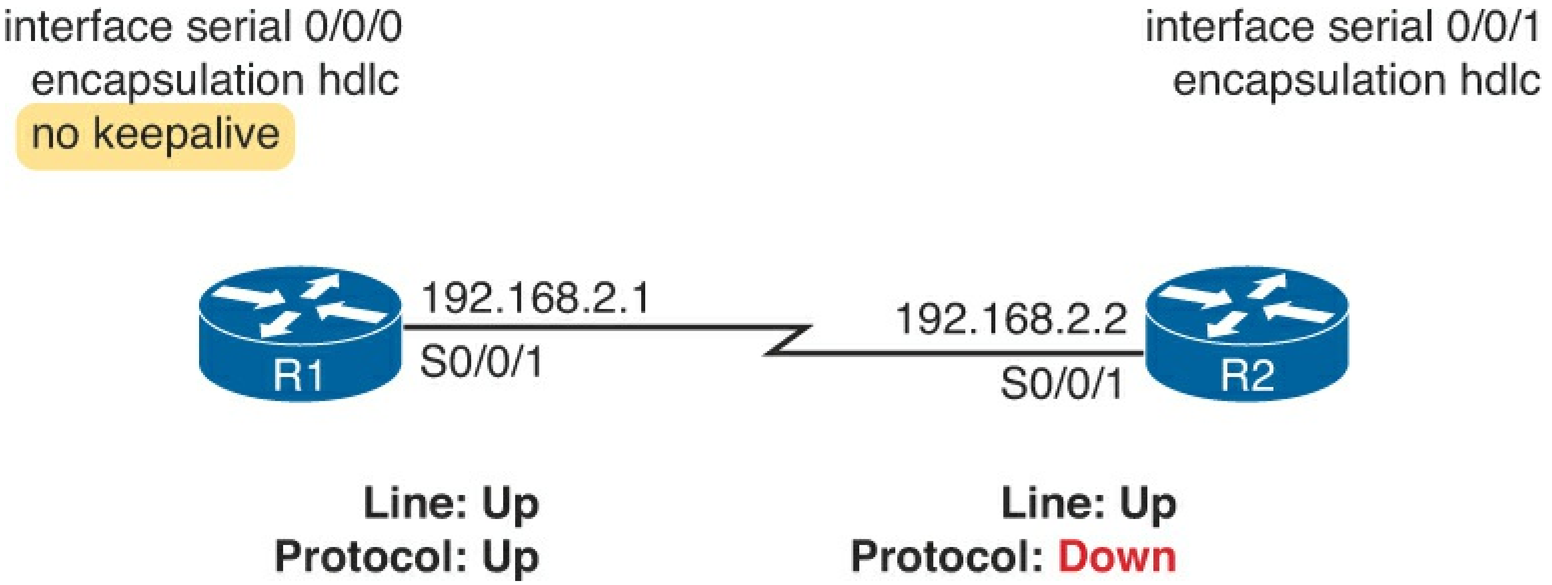
Keepalive Failure

The router *keepalive* feature helps a router notice when a link is no longer functioning. Once a router believes the link no longer works, the router can bring down the interface, allowing the routing protocol to converge to use other routes it they exist.

The keepalive function causes routers to send keepalive messages to each other every 10 seconds (the default setting). The keepalive message for HDLC is a Cisco proprietary message, whereas PPP defines a keepalive message as part of LCP. Both protocols use a keepalive interval, a timer that defines the time period between keepalives.

Regular keepalives keeps the link up, whereas a lack of keepalives makes the link fail. In particular, if a router does not receive any keepalive messages from the other router for a number of keepalive intervals (three or five intervals by default, depending on the IOS version), the router brings down the interface, thinking that the interface of the other router is no longer working.

As long as both routers use keepalives, or both routers disable keepalives, the link works. However, a mistake can be made in which one end leaves keepalives enabled and one end disables keepalives. This mistake only breaks HDLC links; the PPP keepalive feature prevents the problem. Figure 12-17 shows one such example with HDLC and with R1 mistakenly disabling keepalives.



```
interface serial 0/0/0
 encapsulation hdlc
 no keepalive
```

```
interface serial 0/0/1
 encapsulation hdlc
```

Figure 12-17. Problems That Result in a Down/Down State on Router R2

In the scenario shown in Figure 12-17, R2's interface fails because

- R1 does not send keepalive messages, because keepalives are disabled.
- R2 still expects to receive keepalive messages, because keepalives are enabled.

After not hearing the keepalive messages for a number of keepalive intervals, R2 would fail the link to an up/down state. Over time, R2 might bring the link to an up/up state, and then after three more keepalive intervals fail it back to up/down state.

Example 12-6 shows how to find evidence of this keepalive mismatch. First, it lists enough of the output of the **show interfaces S0/0/0** command on R1 to show the line that confirms R1's **no keepalive** configuration setting. It shows the same command on R2, confirming the keepalive is enabled, and the interface state of up/down.

Example 12-6. Line Problems Because of Keepalive Only on R2

Click here to view code image

```
! R1 disables keepalives, and remains in an up/up state.
R1# show interfaces s0/0/0
Serial0/0/0 is up, line protocol is up
Hardware is WIC MBRD Serial
Description: link to R2
Internet address is 192.168.2.1/24
MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
reliability 255/255, txload 1/255, rxload 1/255
Encapsulation HDLC, loopback not set
Keepalive not set
! lines omitted for brevity
```

```
! Below, R2 still has keepalives enabled (default)
R2# show interfaces S0/0/1
Serial0/0/1 is up, line protocol is down
Hardware is WIC MBRD Serial
Internet address is 192.168.2.2/24
MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
    reliability 255/255, txload 1/255, rxload 1/255
    Encapsulation HDLC, loopback not set
    Keepalive set (10 sec)
    ! lines omitted for brevity
```

PAP and CHAP Authentication Failure

As mentioned earlier, a failure in the PAP/CHAP authentication process results in both routers falling to an up and down state. To discover whether a PAP/CHAP failure is really the root cause, you can use the **debug ppp authentication** command. For perspective, Example 12-7 shows the output of this command when CHAP has been configured as in earlier Example 12-5, with CHAP working correctly in this case.

Example 12-7. Debug Messages Confirming the Correct Operation of CHAP

Click here to view code image

```
R1# debug ppp authentication
PPP authentication debugging is on
R1#
*Nov 18 23:34:30.060: %LINK-3-UPDOWN: Interface Serial0/0/0, changed state to up
*Nov 18 23:34:30.060: Se0/0/0 PPP: Using default call direction
*Nov 18 23:34:30.060: Se0/0/0 PPP: Treating connection as a dedicated line
*Nov 18 23:34:30.060: Se0/0/0 PPP: Session handle[58000009] Session id[7]
*Nov 18 23:34:30.064: Se0/0/0 CHAP: O CHALLENGE id 1 len 23 from "R1"
*Nov 18 23:34:30.084: Se0/0/0 CHAP: I CHALLENGE id 1 len 23 from "R2"
*Nov 18 23:34:30.084: Se0/0/0 PPP: Sent CHAP SENDAUTH Request
*Nov 18 23:34:30.084: Se0/0/0 CHAP: I RESPONSE id 1 len 23 from "R2"
*Nov 18 23:34:30.084: Se0/0/0 PPP: Received SENDAUTH Response PASS
*Nov 18 23:34:30.084: Se0/0/0 CHAP: Using hostname from configured hostname
*Nov 18 23:34:30.084: Se0/0/0 CHAP: Using password from AAA
*Nov 18 23:34:30.084: Se0/0/0 CHAP: O RESPONSE id 1 len 23 from "R1"
*Nov 18 23:34:30.084: Se0/0/0 PPP: Sent CHAP LOGIN Request
*Nov 18 23:34:30.084: Se0/0/0 PPP: Received LOGIN Response PASS
*Nov 18 23:34:30.088: Se0/0/0 CHAP: O SUCCESS id 1 len 4
*Nov 18 23:34:30.088: Se0/0/0 CHAP: I SUCCESS id 1 len 4
```

CHAP uses a three-message exchange, as shown back in Figure 12-14, with a set of messages flowing for authentication in each direction by default. The three highlighted lines show the authentication process by which R1 authenticates R2, as follows:

1. This line refers to a CHAP Challenge message, sent out of router R1, per the *O*, meaning “output.” The end of the line confirms it was sent from the router with hostname R1.
2. This line refers to a CHAP Response message, sent from router R2, with an *I* for “input,” meaning the messages comes into R1.
3. This line refers to a CHAP Success message, sent out (*O*) by R1, stating that the authentication was successful.

You can see the same three messages for R2’s authentication of R1 in the output, as well, but those messages are not highlighted in the example.

When CHAP authentication fails, the **debug** output shows a couple of fairly obvious messages. Example 12-8 shows the results using the same two-router internetwork shown in Figure 12-15, which was used for the CHAP configuration example. However, this time, the passwords are misconfigured, so CHAP fails.

Example 12-8. Debug Messages Confirming the Failure of CHAP

Click here to view code image

```
R1# debug ppp authentication
PPP authentication debugging is on
! Lines omitted for brevity
*Nov 18 23:45:48.820: Se0/0/0 CHAP: O CHALLENGE id 1 len 23 from "R1"
*Nov 18 23:45:48.820: Se0/0/0 CHAP: I RESPONSE id 1 len 23 from "R2"
*Nov 18 23:45:48.820: Se0/0/0 CHAP: O FAILURE id 1 len 25 msg is "Authentication
failed"
```

Troubleshooting Layer 3 Problems

This chapter suggests that the best starting place to troubleshoot serial links is to ping the IP address of the router on the other end of the link—specifically, the IP address on the serial link. Interestingly, the serial link can be in an up and up state but the ping can still fail because of Layer 3 misconfiguration. In some cases, the ping may work but the routing protocols might not be able to exchange routes. This short section examines the symptoms, which differ slightly depending on whether HDLC or PPP is used and the root cause.

First, consider an HDLC link on which the physical and data link details are working fine. In this case, both routers' interfaces are in an up and up state. However, if the IP addresses configured on the serial interfaces on the two routers are in different subnets, a ping to the IP address on the other end of the link will fail because the routers do not have a matching route. For example, in Figure 12-17, if R1's serial IP address remained 192.168.2.1, and R2's was changed to 192.168.3.2 (instead of 192.168.2.2), still with a mask of /24, the two routers would have connected routes to different subnets. They would not have a route matching the opposite router's serial IP address.

Finding and fixing a mismatched subnet problem with HDLC links is relatively simple. You can find the problem by doing the usual first step of pinging the IP address on the other end of the link and failing. If both interfaces have a status of up/up, the problem is likely this mismatched IP subnet.

For PPP links with the same IP address/mask misconfiguration, the ping to the other router's IP address actually works. However, the IP subnet mismatch still prevents EIGRP and OSPF neighbor relationships from forming, so it is still a good idea to follow the rules and put both serial interface IP addresses in the same subnet.

PPP makes the ping work with the mismatched subnet by adding a host route, with a /32 prefix length, for the IP address of the other router. This happens as part of the IP Control Protocol work. Example 12-9 shows this exact scenario.

> **Note**
>
> A route with a /32 prefix, representing a single host, is called a *host route*.

Example 12-9. PPP Allowing a Ping over a Serial Link, Even with Mismatched Subnets

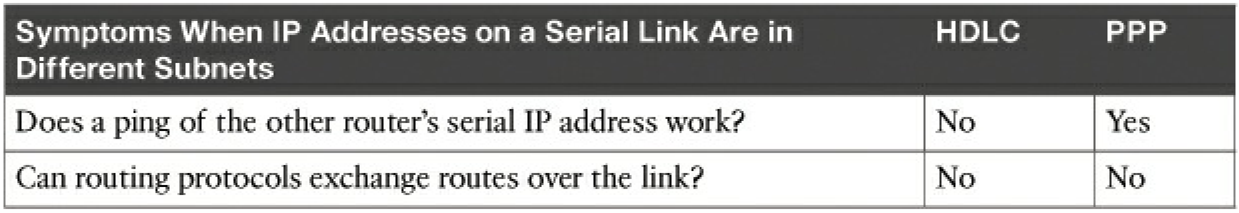
Click here to view code image

```
R1# show ip route
! Legend omitted for brevity
192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
C 192.168.1.0/24 is directly connected, GigabitEthernet0/0
L 192.168.1.1/32 is directly connected, GigabitEthernet0/0
192.168.2.0/24 is variably subnetted, 2 subnets, 2 masks
C 192.168.2.0/24 is directly connected, Serial0/0/0
L 192.168.2.1/32 is directly connected, Serial0/0/0
192.168.3.0/32 is subnetted, 1 subnets
C 192.168.3.2 is directly connected, Serial0/0/0

R1# ping 192.168.3.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.3.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/2/4 ms
```

The first highlighted line in the example shows the normal connected route on the serial link, for network 192.168.2.0/24. R1 thinks this subnet is the subnet connected to S0/0/0 because of R1's configured IP address (192.168.2.1/24). The second highlighted line shows the host route created by PPP, specifically for R2's new serial IP address (192.168.3.2). (R2 will have a similar route for 192.168.2.1/32, R1's serial IP address.) So, both routers have a route to allow them to forward packets to the IP address on the other end of the link, even though the other router's address is in a different subnet. This extra host route allows the ping to the other side of the serial link to work in spite of the addresses on each end being in different subnets.

Table 12-7 summarizes the behavior on HDLC and PPP links when the IP addresses on each end do not reside in the same subnet but no other problems exist.

Table 12-7. Summary of Symptoms for Mismatched Subnets on Serial Links



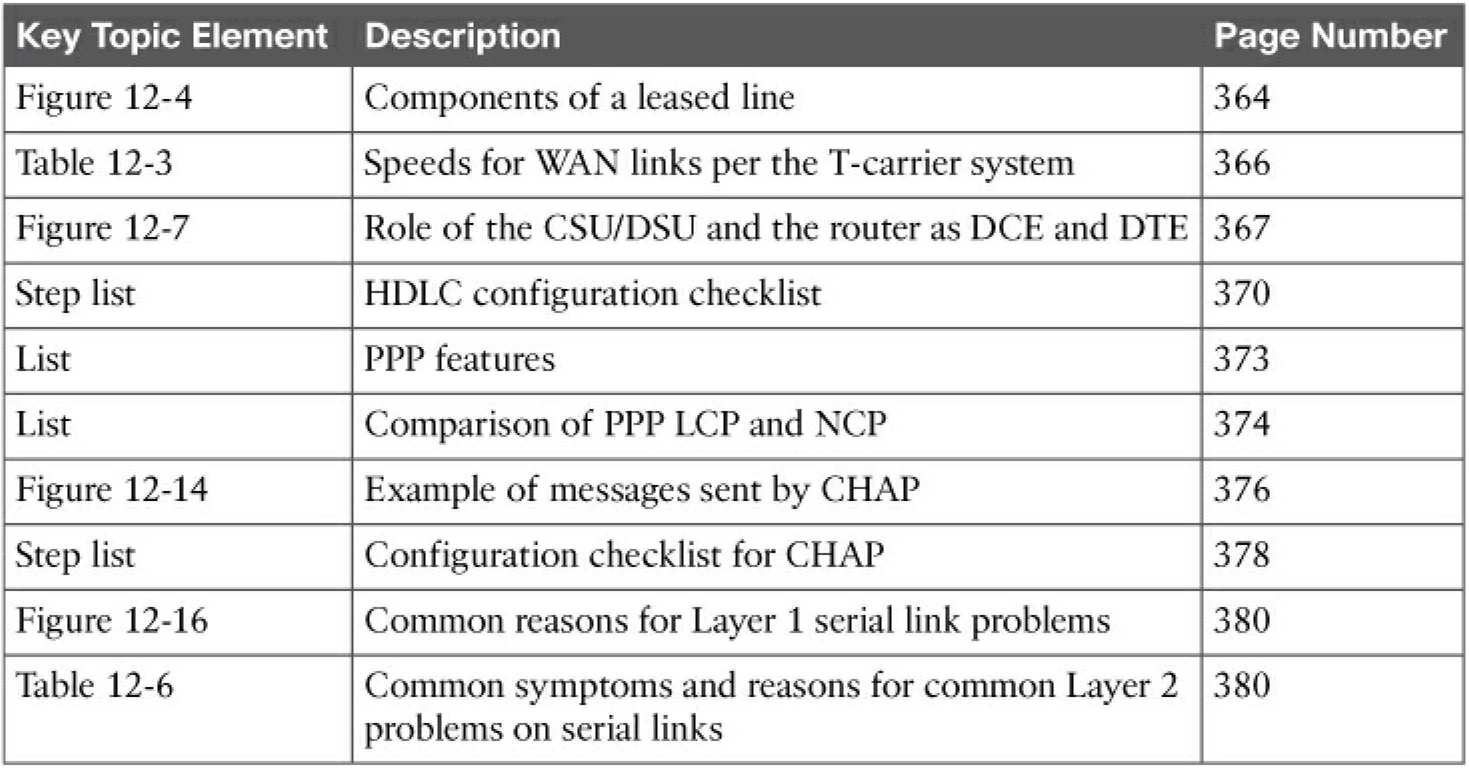
Symptoms When IP Addresses on a Serial Link Are in Different Subnets	HDLC	PPP
Does a ping of the other router's serial IP address work?	No	Yes
Can routing protocols exchange routes over the link?	No	No

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 12-8 lists these key topics and where each is discussed.

Table 12-8. Key Topics for Chapter 12



Key Topic Element	Description	Page Number
Figure 12-4	Components of a leased line	364
Table 12-3	Speeds for WAN links per the T-carrier system	366
Figure 12-7	Role of the CSU/DSU and the router as DCE and DTE	367
Step list	HDLC configuration checklist	370
List	PPP features	373
List	Comparison of PPP LCP and NCP	374
Figure 12-14	Example of messages sent by CHAP	376
Step list	Configuration checklist for CHAP	378
Figure 12-16	Common reasons for Layer 1 serial link problems	380
Table 12-6	Common symptoms and reasons for common Layer 2 problems on serial links	380

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix D, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix E, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22 directs you in how to use these terms for late-stage preparation for the exam.

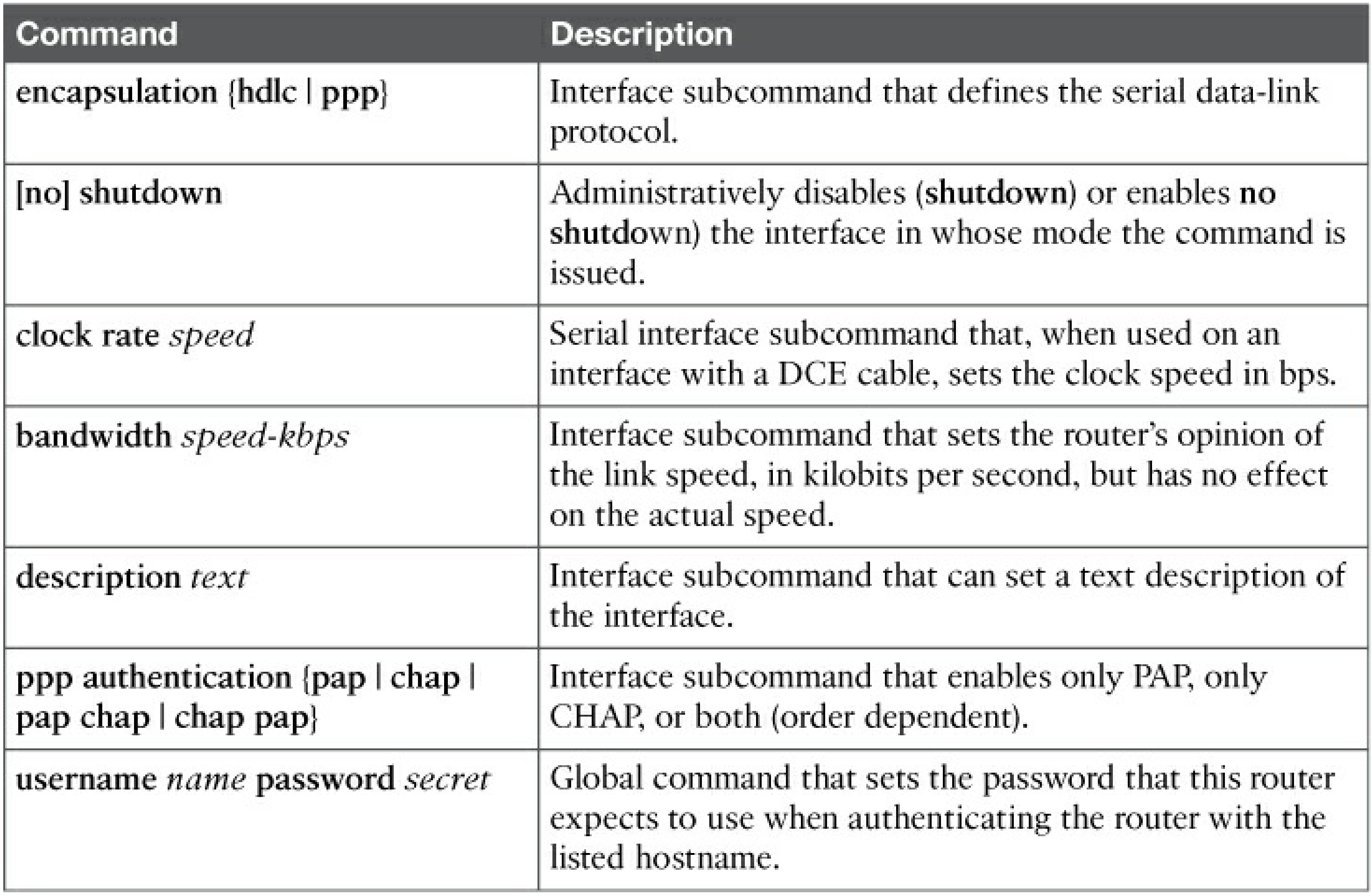
leased line
telco
serial link
WAN link
T1
DS0
DS1
T3
customer premise equipment
CSU/DSU
serial cable
DCE

DTE
HDLC
PPP
CHAP
IP control protocol
keepalive
Link Control Protocol

Command Reference to Check Your Memory

Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table, read the descriptions on the right side, and see if you remember the command.

Table 12-9. Chapter 12 Configuration Command Reference



Command	Description
encapsulation {hdlc | ppp}	Interface subcommand that defines the serial data-link protocol.
[no] shutdown	Administratively disables (**shutdown**) or enables **no shutdown**) the interface in whose mode the command is issued.
clock rate *speed*	Serial interface subcommand that, when used on an interface with a DCE cable, sets the clock speed in bps.
bandwidth *speed-kbps*	Interface subcommand that sets the router's opinion of the link speed, in kilobits per second, but has no effect on the actual speed.
description *text*	Interface subcommand that can set a text description of the interface.
ppp authentication {pap | chap | pap chap | chap pap}	Interface subcommand that enables only PAP, only CHAP, or both (order dependent).
username *name* **password** *secret*	Global command that sets the password that this router expects to use when authenticating the router with the listed hostname.

Table 12-10. Chapter 12 EXEC Command Reference

Command	Description
show interfaces [*type number*]	Lists statistics and details of interface configuration, including the encapsulation type.
show interfaces [*type number*] **description**	Lists a single line per interface (or if the interface is included, just one line of output total) that lists the interface status and description.
show ip interface brief	Lists one line of output per interface, with IP address and interface status.
show controllers serial *number*	Lists whether a cable is connected to the interface, and if so, whether it is a DTE or DCE cable.
debug ppp authentication	Generates messages for each step in the PAP or CHAP authentication process.
debug ppp negotiation	Generates **debug** messages for the LCP and NCP negotiation messages sent between the devices.

Chapter 13. Understanding Frame Relay Concepts

This chapter covers the following exam topics:

WAN Technologies

Identify Different WAN Technologies

Frame Relay

Frame Relay was at one time the most popular WAN technology used in computer networks. Today, Frame Relay has become less popular, being replaced by several other WAN options. These include the virtual private network (VPN) technology, as discussed back in Chapter 7, "Virtual Private Networks," and Ethernet WANs, as introduced in the ICND1 book. In addition, many enterprises use Multiprotocol Label Switching (MPLS) VPNs, which follow the same basic service model as Frame Relay, usually offered by the same Frame Relay providers but with significant technical advantages.

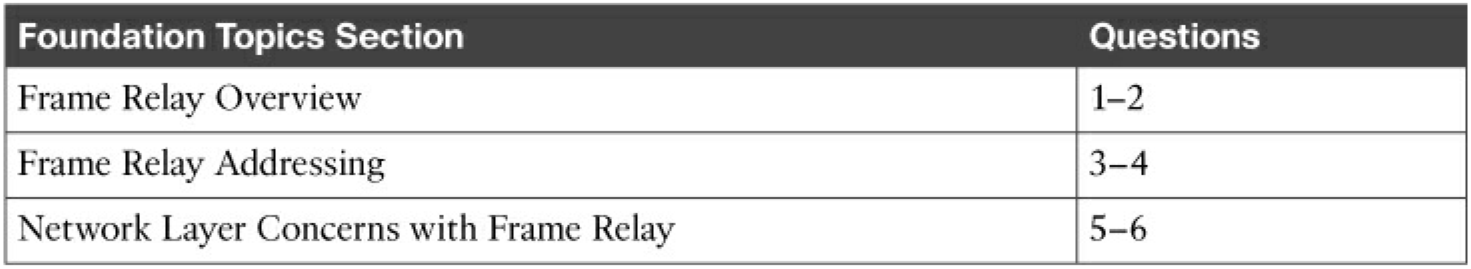
Although many companies choose other WAN options today, Frame Relay still has uses. Some companies still use it as a core WAN technology. It can also be used to connect to MPLS and Internet VPNs. So, Frame Relay will be an important networking topic for some time.

This chapter describes Frame Relay protocol details, with Chapter 14, "Implementing Frame Relay," discussing how to configure Frame Relay. The first section of this chapter focuses on the basics of Frame Relay, including a lot of new terminology. The second section examines Frame Relay data link addressing. This topic requires some attention because Frame Relay addresses are needed for both router configuration and troubleshooting. The last major section of this chapter examines some network layer concerns when using Frame Relay.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the Exam Preparation Tasks section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 13-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Frame Relay Overview	1–2
Frame Relay Addressing	3–4
Network Layer Concerns with Frame Relay	5–6

1. Which of the following is a protocol used between the Frame Relay DTE and the Frame Relay switch?

- **a.** VC
- **b.** CIR
- **c.** LMI
- **d.** Q.921
- **e.** DLCI

2. Which of the following statements about Frame Relay are true? (Choose two answers.)

- **a.** The DTE usually sits at the customer site.
- **b.** Routers send LMI messages to each other to signal the status of a VC.
- **c.** A frame's source DLCI must remain unchanged, but the frame's destination DLCI is allowed to change, as the frame traverses the Frame Relay cloud.
- **d.** The Frame Relay encapsulation type on the sending router should match the encapsulation type on the receiving router for the receiving router to be able to understand the frame's contents.

3. What does DLCI stand for?

- **a.** Data link connection identifier
- **b.** Data link connection indicator
- **c.** Data link circuit identifier
- **d.** Data link circuit indicator

4. Router R1 receives a frame from router R2 with DLCI value 222 in it. Which of the following statements about this network is the most accurate?

- **a.** 222 represents Router R1.
- **b.** 222 represents Router R2.
- **c.** 222 is the local DLCI on R1 that represents the VC between R1 and R2.
- **d.** 222 is the local DLCI on R2 that represents the VC between R1 and R2.

5. FredsCo has five sites, with routers connected to the same Frame Relay network. Virtual circuits (VC) have been defined between each pair of routers. What is the fewest subnets that FredsCo could use on the Frame Relay network?
   - **a.** 1
   - **b.** 2
   - **c.** 3
   - **d.** 4
   - **e.** 5
   - **f.** 10
6. BarneyCo has 10 sites with routers connected to the same Frame Relay network. VCs have been defined between each pair of routers. Barney, the company president, will fire anyone who configures Frame Relay without using point-to-point subinterfaces. What is the fewest number of subnets that BarneyCo could use on the Frame Relay network?
   - **a.** 1
   - **b.** 4
   - **c.** 8
   - **d.** 10
   - **e.** 12
   - **f.** 15

Answers to the "Do I Know This Already?" quiz:

1 C **2** A and D **3** A **4** C **5** A **6** D

Foundation Topics

Frame Relay Overview

Frame Relay networks provide more features and benefits than simple point-to-point WAN links, but to do that, Frame Relay protocols are more detailed. For example, Frame Relay networks are multiaccess networks, which means that more than two devices can attach to the network, similar to LANs. Unlike with LANs, you cannot send a data link layer broadcast over Frame Relay. Therefore, Frame Relay networks are called nonbroadcast multiaccess (NBMA) networks. Also, because Frame Relay is multiaccess, it requires the use of an address that identifies to which remote router each frame is addressed.

Figure 13-1 outlines the basic physical topology and related terminology in a Frame Relay network.

Key Topic

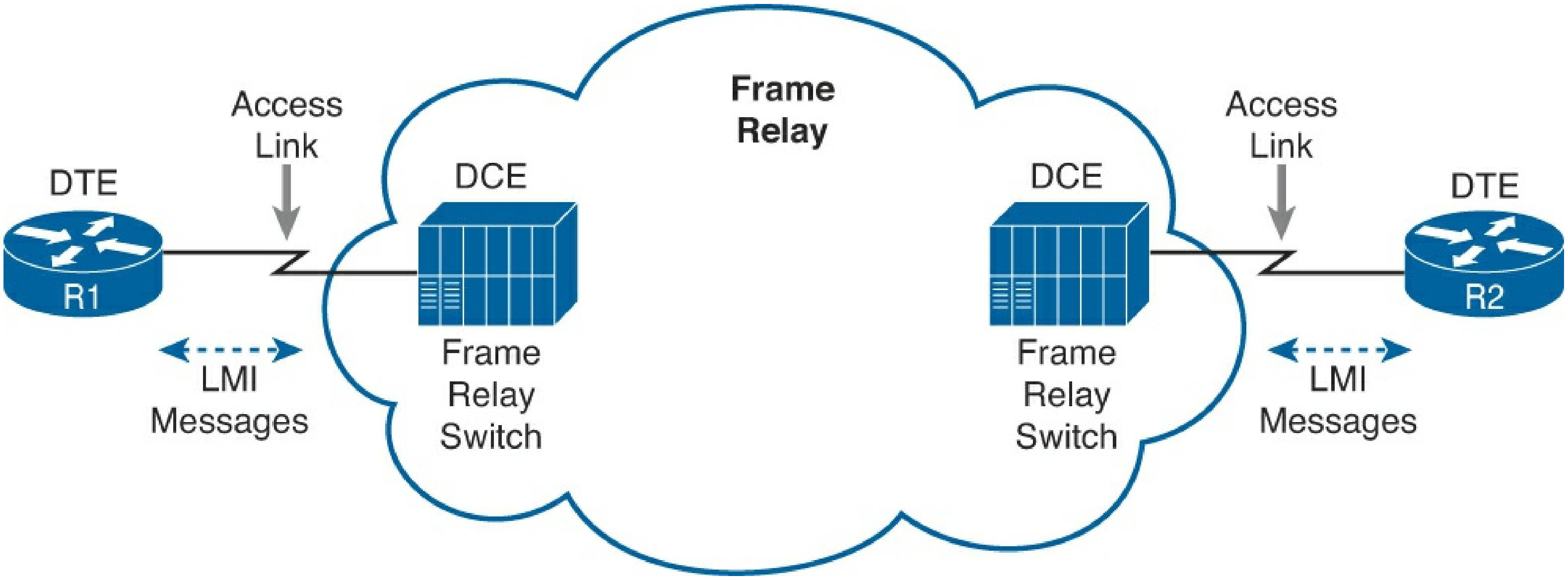


Figure 13-1. Frame Relay Components

Figure 13-1 shows the most basic components of a Frame Relay network. A leased line is installed between the router and a nearby Frame Relay switch; this link is called the *access link*. To ensure that the link is working, the device outside the Frame Relay network, called the data terminal equipment (DTE), exchanges regular messages with the Frame Relay switch. These keepalive messages, along with other messages, are defined by the Frame Relay Local Management Interface (LMI) protocol. The routers are considered DTE, and the Frame Relay switches are data communications equipment (DCE).

Note

The terms *DCE* and *DTE* have different meanings in different contexts. Here, with a Frame Relay service, the roles are as described in the previous paragraph. On a physical leased line, the DCE provides Layer 1 clocking, and the DTE receives and reacts to the DCE's clock signal. These are two different (and accepted) uses of the same two terms.

Figure 13-1 shows the physical connectivity at each connection to the Frame Relay network, and Figure 13-2 shows the logical, or virtual, end-to-end connectivity associated with a virtual circuit (VC).

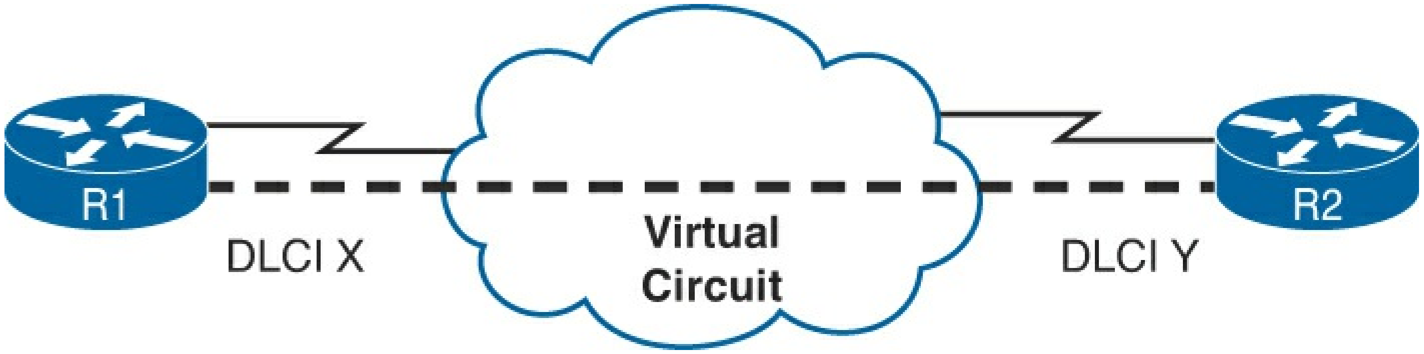


Figure 13-2. Frame Relay PVC Concepts

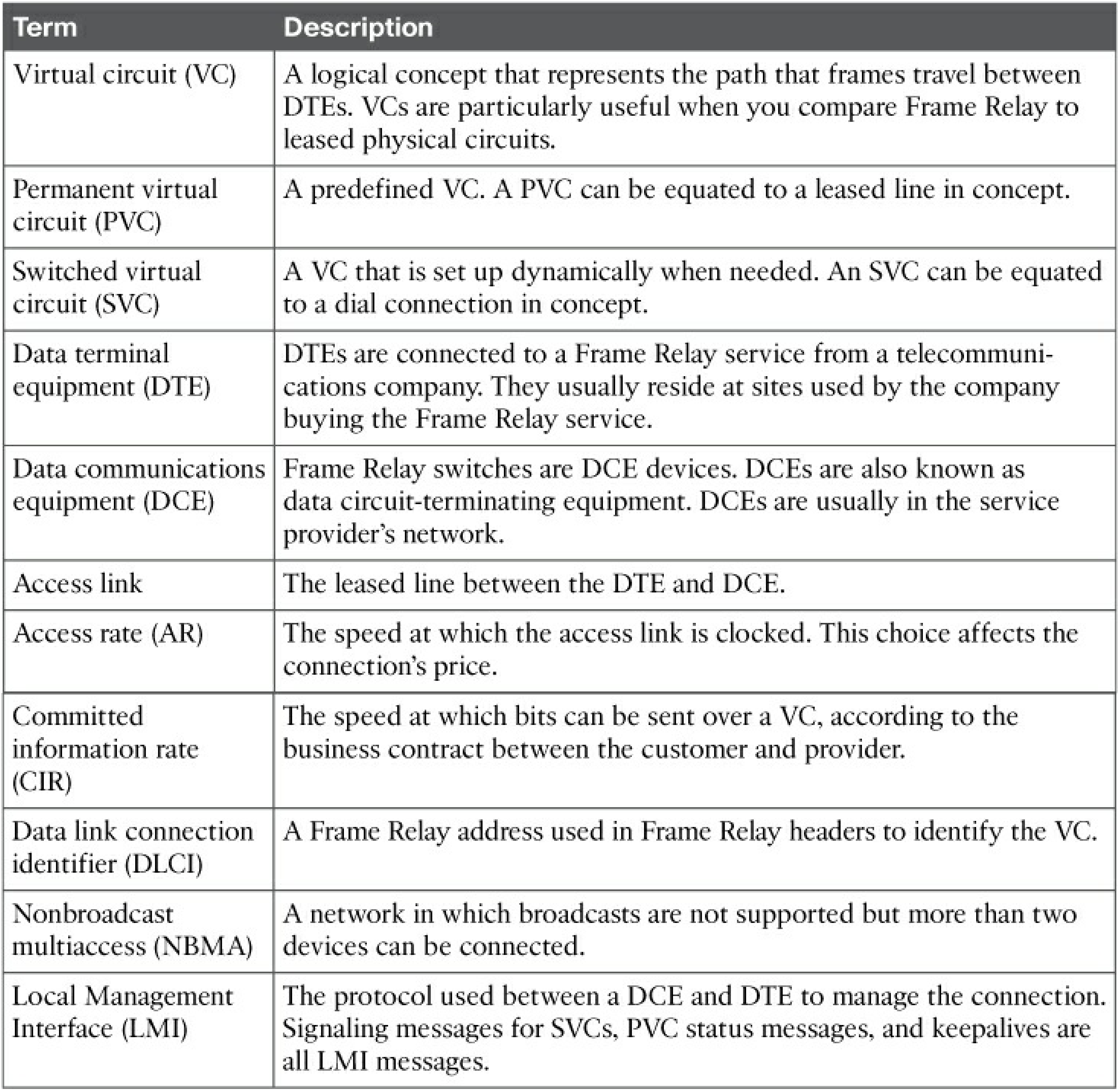
The logical communications path between each pair of DTEs is a VC. The dashed line in the figure represents a single VC; this book uses a thick dashed line style to make sure that you notice the line easily. The service provider usually preconfigures all the required details of a VC; predefined VCs are called permanent virtual circuits (PVC).

Routers use the data link connection identifier (DLCI) as the Frame Relay address; it identifies the VC over which the frame should travel. So, in Figure 13-2, when R1 needs to forward a packet to R2, R1 encapsulates the Layer 3 packet into a Frame Relay header and trailer and then sends the frame. The Frame Relay header includes the correct DLCI, identifying the PVC connecting R1 to R2, so that the provider's Frame Relay switches correctly forward the frame to R2.

Table 13-2 lists the components shown in Figures 13-1 and 13-2 and some associated terms. After the table, the most important features of Frame Relay are described in further detail.

Key Topic

Table 13-2. Frame Relay Terms and Concepts



Term	Description
Virtual circuit (VC)	A logical concept that represents the path that frames travel between DTEs. VCs are particularly useful when you compare Frame Relay to leased physical circuits.
Permanent virtual circuit (PVC)	A predefined VC. A PVC can be equated to a leased line in concept.
Switched virtual circuit (SVC)	A VC that is set up dynamically when needed. An SVC can be equated to a dial connection in concept.
Data terminal equipment (DTE)	DTEs are connected to a Frame Relay service from a telecommunications company. They usually reside at sites used by the company buying the Frame Relay service.
Data communications equipment (DCE)	Frame Relay switches are DCE devices. DCEs are also known as data circuit-terminating equipment. DCEs are usually in the service provider's network.
Access link	The leased line between the DTE and DCE.
Access rate (AR)	The speed at which the access link is clocked. This choice affects the connection's price.
Committed information rate (CIR)	The speed at which bits can be sent over a VC, according to the business contract between the customer and provider.
Data link connection identifier (DLCI)	A Frame Relay address used in Frame Relay headers to identify the VC.
Nonbroadcast multiaccess (NBMA)	A network in which broadcasts are not supported but more than two devices can be connected.
Local Management Interface (LMI)	The protocol used between a DCE and DTE to manage the connection. Signaling messages for SVCs, PVC status messages, and keepalives are all LMI messages.

The definitions for Frame Relay are contained in documents from the International Telecommunications Union (ITU) and the American National Standards Institute (ANSI). Originally, back in the 1990s, the Frame Relay Forum, a vendor consortium, defined many of the original specifications. Over time, the ITU and ANSI picked up many of the forum's standards.

Now that you have heard some of the big ideas and key terms from Frame Relay, the next few topics go into more depth about the core functions within Frame Relay: virtual circuits, the LMI protocol, framing, and Frame Relay addressing.

Virtual Circuits

Frame Relay provides significant advantages over simply using point-to-point leased lines. The primary advantage has to do with VCs. Consider Figure 13-3, which shows a typical Frame Relay network with three sites.

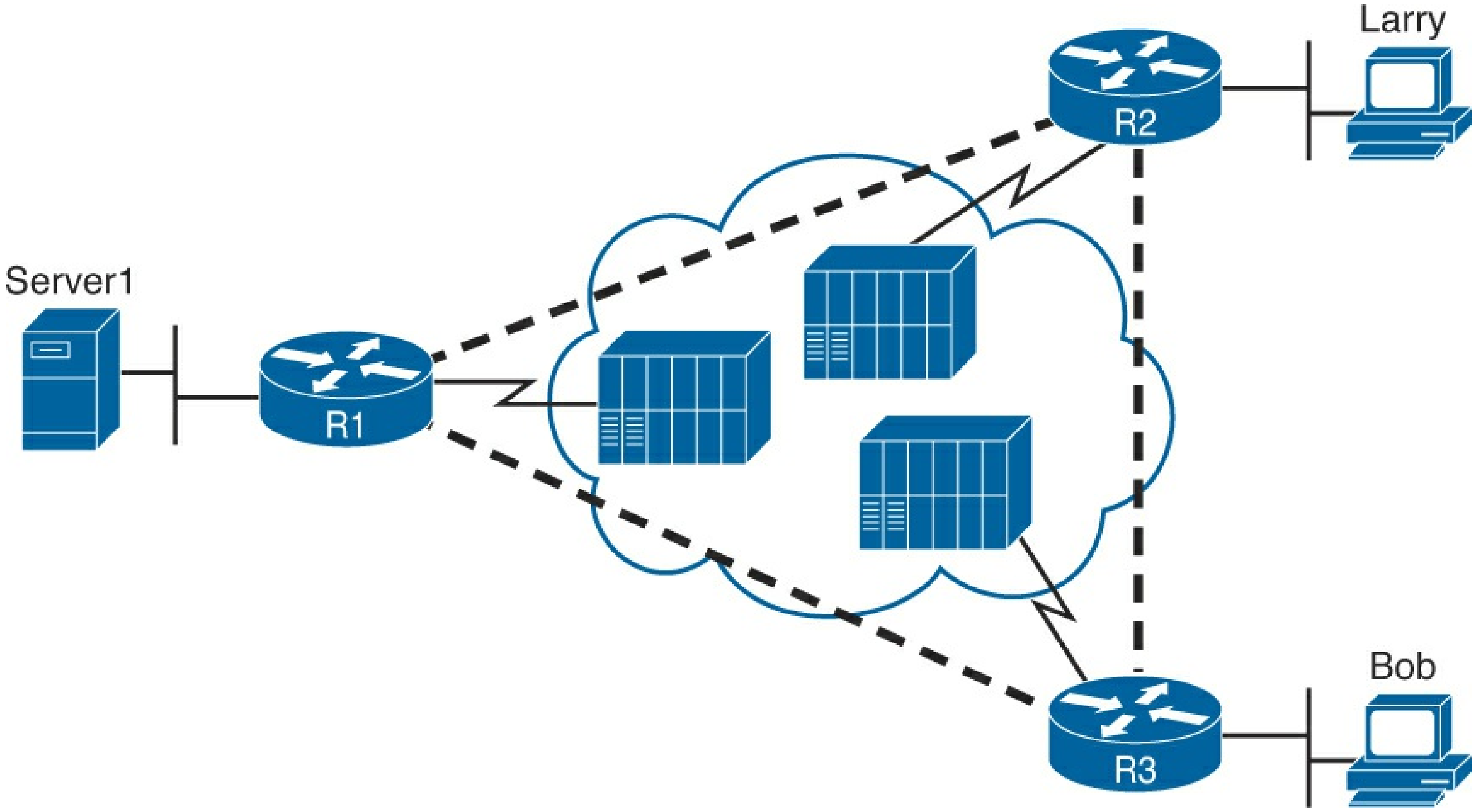


Figure 13-3. Typical Frame Relay Network with Three Sites

A VC defines a logical path between two Frame Relay DTEs. The term *virtual circuit* describes the concept well. It acts like a point-to-point circuit, enabling the sending of data between two endpoints over a WAN. There is no physical circuit directly between the two endpoints, so it is virtual. For example, R1 terminates two VCs—one whose other endpoint is R2, and one whose other endpoint is R3. R1 can send traffic directly to either of the other two routers by sending it over the appropriate VC.

VCs share the access link and the Frame Relay network. For example, both VCs terminating at R1 use the same access link. R1 can send one Frame Relay frame to R2, and then another frame to R3, sending both over the same physical access link.

Not only does a single customer router share its access link among many VCs, many customers share the same Frame Relay network. Originally, people with leased-line networks were reluctant to migrate to Frame Relay because they would be competing with other Frame Relay customers for the provider’s capacity inside the cloud. To address these fears, Frame Relay uses a concept of a committed information rate (CIR). Each VC has a CIR, which is a guarantee by the provider that a particular VC gets at least that much bandwidth. So, you can migrate from a leased line to Frame Relay, getting a CIR of at least as much bandwidth as you previously had with your leased line.

One big advantage of Frame Relay over leased lines is that Frame Relay provides connectivity to each site, with only a single access link between each router and the Frame Relay provider. Interestingly, even with a three-site network, it’s probably less expensive to use Frame Relay than to use point-to-point links because the access links tend to be relatively short, to some nearby Frame Relay provider point of presence (PoP).

Frame Relay and other multiaccess WAN technologies have an even bigger cost advantage with larger enterprise WANs. For instance, imagine an organization with 100 sites, with one router at each site. To connect each pair of routers with a leased line, that company would need 4950 leased lines! And besides that, each router would need 99 serial interfaces. With Frame Relay, each router could use one serial interface and one access link into the Frame Relay cloud, for a total of 100 access links. Then, the Frame Relay provider could create a PVC between each pair of routers (a total of 4950 VCs). The Frame Relay solution requires a lot fewer actual physical links, and you would need only one serial interface on each router.

Service providers can build their Frame Relay networks more cost-effectively than for leased lines. As you would expect, that makes it less expensive for the Frame Relay customer as well. For connecting many WAN sites, Frame Relay is simply more cost-effective than leased lines.

When the Frame Relay network is engineered, the design might not include a VC between each pair of sites. Figure 13-3 includes PVCs between each pair of sites; this is called a *full-mesh* Frame Relay network. When not all pairs have a direct PVC, it is called a *partial-mesh network*. Figure 13-4 shows the same network as Figure 13-3, but this time with a partial mesh and only two PVCs. This is typical when R1 is at the main site and R2 and R3 are at remote offices that rarely need to communicate directly.

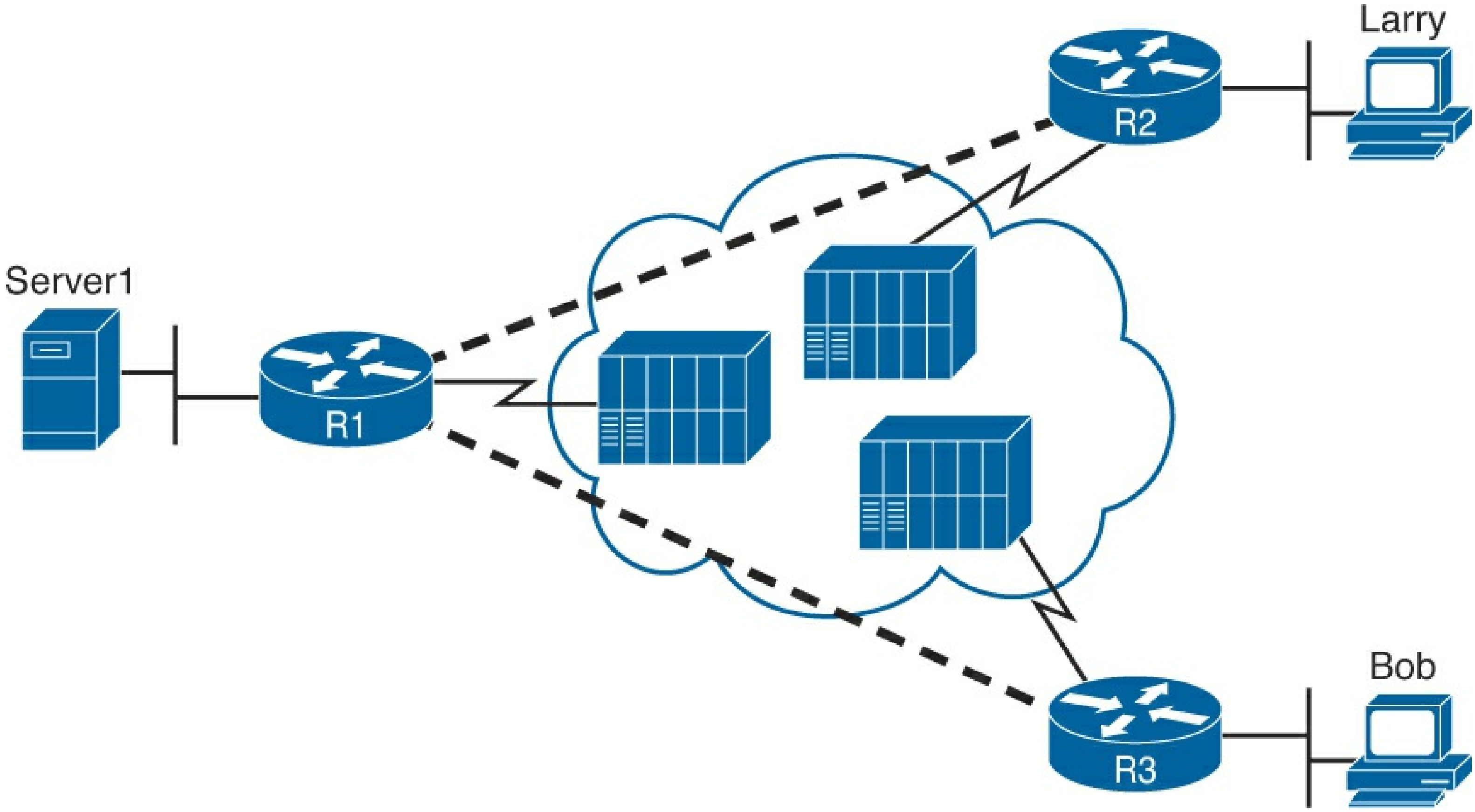


Figure 13-4. Typical Partial-Mesh Frame Relay Network

The partial mesh has some advantages and disadvantages compared to a full mesh. Partial-mesh designs save money compared to full-mesh designs because the provider charges per VC. The downside is that traffic from R2's site to R3's site must go to R1 first and then be forwarded. If that is a small amount of traffic, it is a small price to pay. If it is a lot of traffic, a full mesh is probably worth the extra money because traffic going between two remote sites would have to cross R1's access link twice.

LMI and Encapsulation Types

While the PVC gives two customer routers a logical means to send frames to one another, Frame Relay has many physical and logical components that have to work together to make those PVCs work. Physically, each router needs a physical access link from the router to some Frame Relay switch. The provider has to create some kind of physical network between those switches, as well. In addition, the provider has to do some work so that the frames sent over one PVC arrive at the correct destination.

Frame Relay uses the Local Management Interface (LMI) protocol to manage each physical access link and the PVCs that use that link. These LMI messages flow between the DTE (for example, a router) and the DCE (for example, the Frame Relay switch owned by the service provider).

The most important LMI message relating to topics on the exam is the LMI status inquiry message. LMI status messages perform two key functions:

Key Topic

- They perform a keepalive function between the DTE and DCE. If the access link has a problem, the absence of keepalive messages implies that the link is down.
- They signal whether a PVC is active or inactive. Even though each PVC is predefined, its status can change. An access link might be up, but one or more VCs could be down. The router needs to know which VCs are up and which are down. It learns that information from the switch using LMI status messages.

Interestingly, due to historical reasons, Cisco routers have three options for different variations of LMI protocols: Cisco, ITU, and ANSI. Each LMI option differs slightly and therefore is incompatible with the other two. As long as both the DTE and DCE on each end of an access link use the same LMI standard, LMI works fine.

Configuring the LMI type is easy. Today's most popular option is to use the default LMI setting. This setting uses the LMI autosense feature, in which the router simply figures out which LMI type the switch is using. So, you can simply let the router autosense the LMI and never bother coding the LMI type. If you choose to configure the LMI type, the router disables the autosense feature. Table 13-3 outlines the three LMI types, their origin, and the keyword used in the Cisco IOS software **frame-relay lmi-type** interface subcommand.

Table 13-3. Frame Relay LMI Types

Name	Document	IOS LMI-Type Parameter
Cisco	Proprietary	cisco
ANSI	T1.617 Annex D	ansi
ITU	Q.933 Annex A	q933a

Frame Relay Encapsulation and Framing

A Frame Relay-connected router encapsulates each Layer 3 packet inside a Frame Relay header and trailer before it is sent out an access link. The header and trailer are defined by Frame Relay (or more specifically, the Link Access Procedure Frame Bearer Services [LAPF] specification, ITU Q.922-A). The sparse LAPF framing provides error detection with an FCS in the trailer, a DLCI field (discussed in detail later in this chapter), plus a few other header fields. Figure 13-5 diagrams the frame.

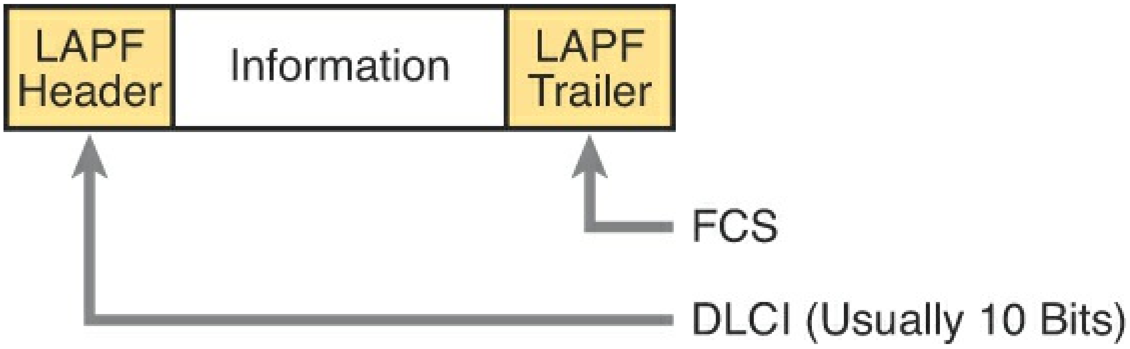


Figure 13-5. LAPF Framing

However, routers actually use a longer header than just the standard LAPF header because the standard header does not provide all the fields usually needed by routers. In particular, Figure 13-5 does not show a Protocol Type field. Each data link header needs a field to define the type of packet that follows the data link header. If Frame Relay is using only the LAPF header, DTEs (including routers) cannot support multiprotocol traffic because there is no way to identify the type of protocol in the Information field.

Two solutions were created to compensate for the lack of a Protocol Type field in the standard Frame Relay header:

- Cisco and three other companies created an additional header, which comes between the LAPF header and the Layer 3 packet shown in Figure 13-5. It includes a 2-byte Protocol Type field, with values matching the same field Cisco uses for HDLC.
- RFC 1490 (and later 2427), *Multiprotocol Interconnect over Frame Relay*, defined the second solution. RFC 1490 was written to ensure multivendor interoperability between Frame Relay DTEs. This RFC defines a similar header, also placed between the LAPF header and Layer 3 packet, and includes a Protocol Type field as well as many other options.

Figure 13-6 outlines these two alternatives.

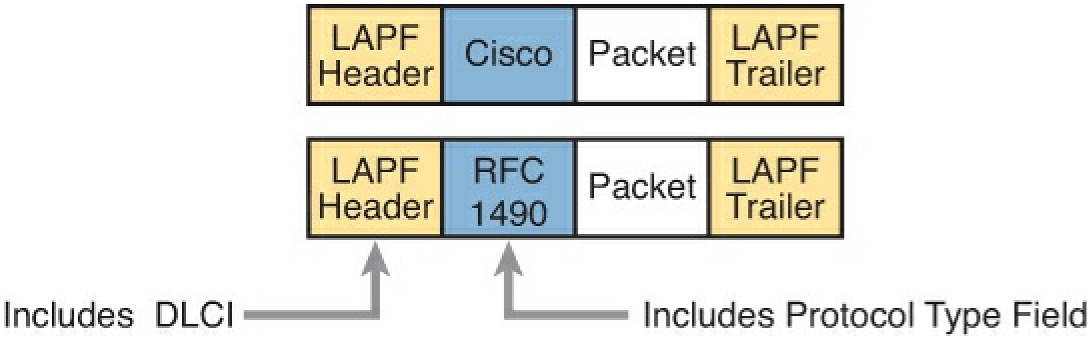


Figure 13-6. Cisco and RFC 1490/2427 Encapsulation

Routers should agree on the encapsulation used; the switches do not care. However, each VC can use a different encapsulation. In the configuration, the encapsulation created by Cisco is called **cisco**, and the other one is called **ietf**.

Now that you have a broad understanding of Frame Relay concepts and terminology, the next section takes a much closer look at Frame Relay DLCIs.

Frame Relay Addressing

At a basic conceptual level, Frame Relay addresses, called data link connection identifiers (DLCI), have some similarity with the more familiar MAC and IP addresses. All these addresses exist as binary values, but they all have some more convenient format: hex for MAC addresses, dotted decimal for IP, and decimal for DLCIs. Frame Relay defines the DLCI as a 10-bit value, written in decimal, with the low-and high-end values usually reserved. (The specific range does not matter much because the service provider assigns the values, but they usually range from around 17 to a little less than 1000.)

When you dig deeper, particularly into how DLCIs impact the forwarding of Frame Relay frames, the similarities to MAC and IP addressing fades, and stark differences appear. This section focuses on that forwarding logic, first discussing the idea that Frame Relay addresses actually identify one end of a PVC. Following that, the discussion turns to the forwarding logic used inside the Frame Relay cloud.

Frame Relay Local Addressing

The service provider assigns each PVC two local DLCI values: one on one end of the PVC, and one for the other end. The term *local DLCI* has several different origins, but you can think of the word *local* as emphasizing the fact that from a router's perspective, the local DLCI is the DLCI used on the local end of the PVC where the router sits. Figure 13-7 shows the idea.

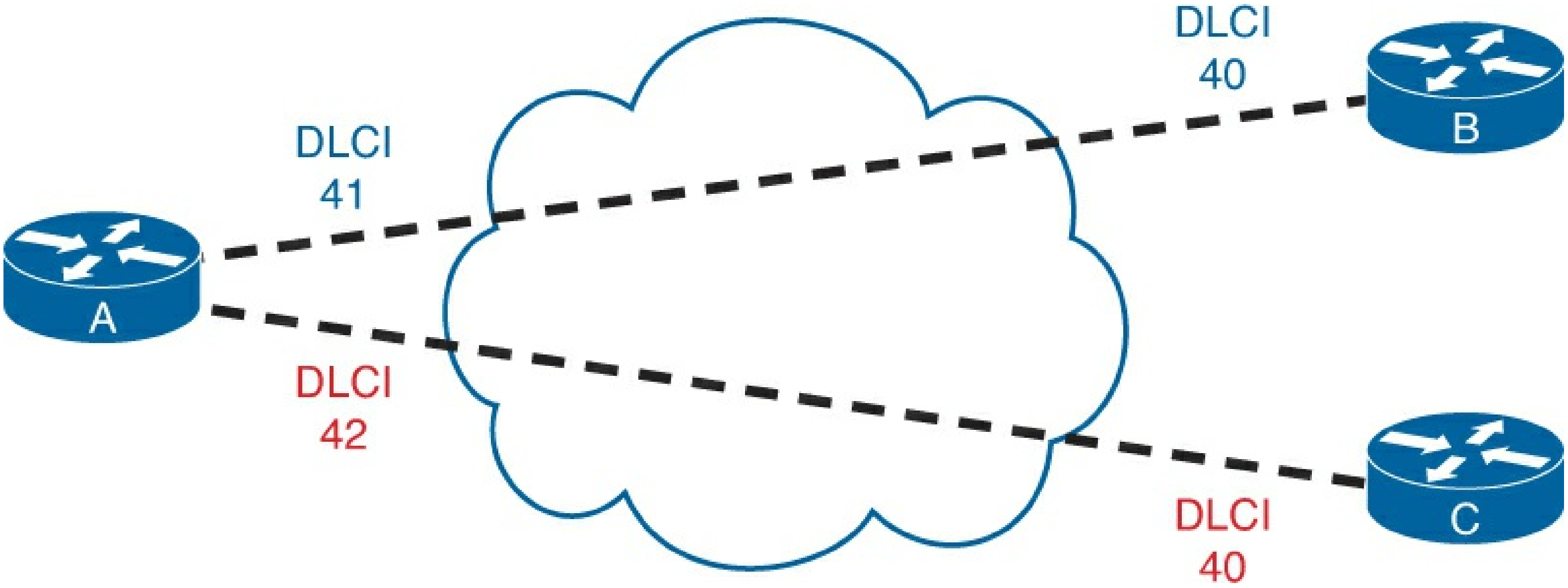


Figure 13-7. Two PVCs, with One DLCI per End of Each PVC

In this example, the PVC between routers A and B has two DLCIs assigned by the provider. Router A's end uses local DLCI 41 to identify the PVC, and router B's end uses DLCI 40 to identify the same PVC. Similarly, the PVC between routers A and C, as usual, has two local DLCIs assigned, one on each end. In this case, router A's end uses 42, and router C's end uses 40.

The service provider could have used any DLCI values within the range of legal values, with one exception:

Key Topic

> The local DLCIs on a single access link must be unique among all PVCs that use one physical Frame Relay access link, because Frame Relay DLCIs are locally significant.

Because the provider chooses the DLCIs, the enterprise network engineer does not need to worry about avoiding making the wrong choice for DLCI value. For the sake of understanding the technology, know that on each physical access link from one router to the Frame Relay network, the DLCI values must be unique. In Figure 13-7, the provider has defined two PVCs that cross R1's one Frame Relay access link: one with local DLCI 41, and one with local DLCI 42. If another PVC were added, connected to router A, the provider just could not use 41 or 42 as the local DLCI on R1's access link.

The local router only sees or knows the local DLCI. When you configure a router, you configure only the local DLCI value, not the DLCI on the other end of the PVC. Likewise, **show** commands list only local DLCI values.

Frame Forwarding with One DLCI Field

The most significant difference between the two other popular addresses in CCNA Routing and Switching (MAC and IP) versus DLCIs relates to the whole forwarding process. The Ethernet header includes both a source and destination MAC address, and the IP header includes a source and destination IP address. However, the Frame Relay header lists only one DLCI field, and it does not identify a source or a destination, but the PVC.

To get an idea of how the provider forwards a Frame Relay frame, consider the fact that the provider knows the local DLCI used on both ends of the PVC, plus the access links that connect to those routers. For instance, in Figure 13-8, the provider knows that a PVC exists between router A and router B. They know it uses local DLCI 41 on the router A side. And they know it uses DLCI 40 on the router B side. Keeping that in mind, take a look at Figure 13-8, which shows what happens when router A sends a frame to router B.

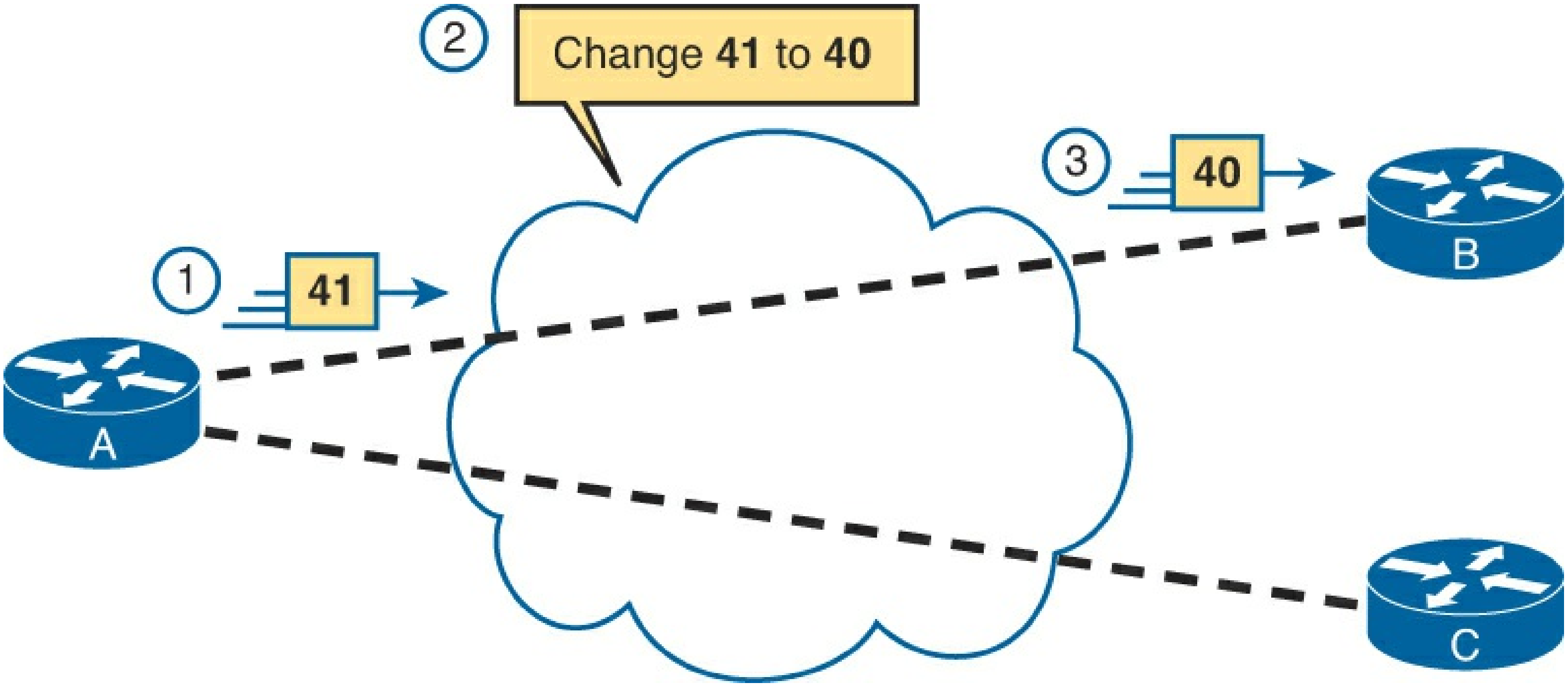


Figure 13-8. Frame Relay Forwarding: Router A to Router B

The figure shows three major steps. First, router A decides to send a frame over the PVC connected to router B. From router A's perspective, A knows that PVC only as the PVC with local DLCI 41, so A sends a frame with DLCI 41 in the header. At Step 2, the service provider does a lot. They look at the information they know about this PVC, forward the frame over toward router B, *and they change the DLCI to 40*. At Step 3, when the frame arrives at router B, it has a DLCI value of 40. Router B correctly thinks that the frame arrived over the PVC from router A, because router B's only knowledge of that PVC is that it is the PVC whose local DLCI (on router B's end) is 40.

Note that when A sent the frame, A used its local DLCI value (41), and when B received the frame, B saw its local DLCI (40).

To complete the process, think about a packet sent by router B back toward router A. Again, the routers only know local DLCI values, so as shown in Figure 13-9, B sends the frame with DLCI 40, which identifies the A-to-B PVC; the cloud changes the DLCI to 41; and router A receives the frame with DLCI 41 in it.

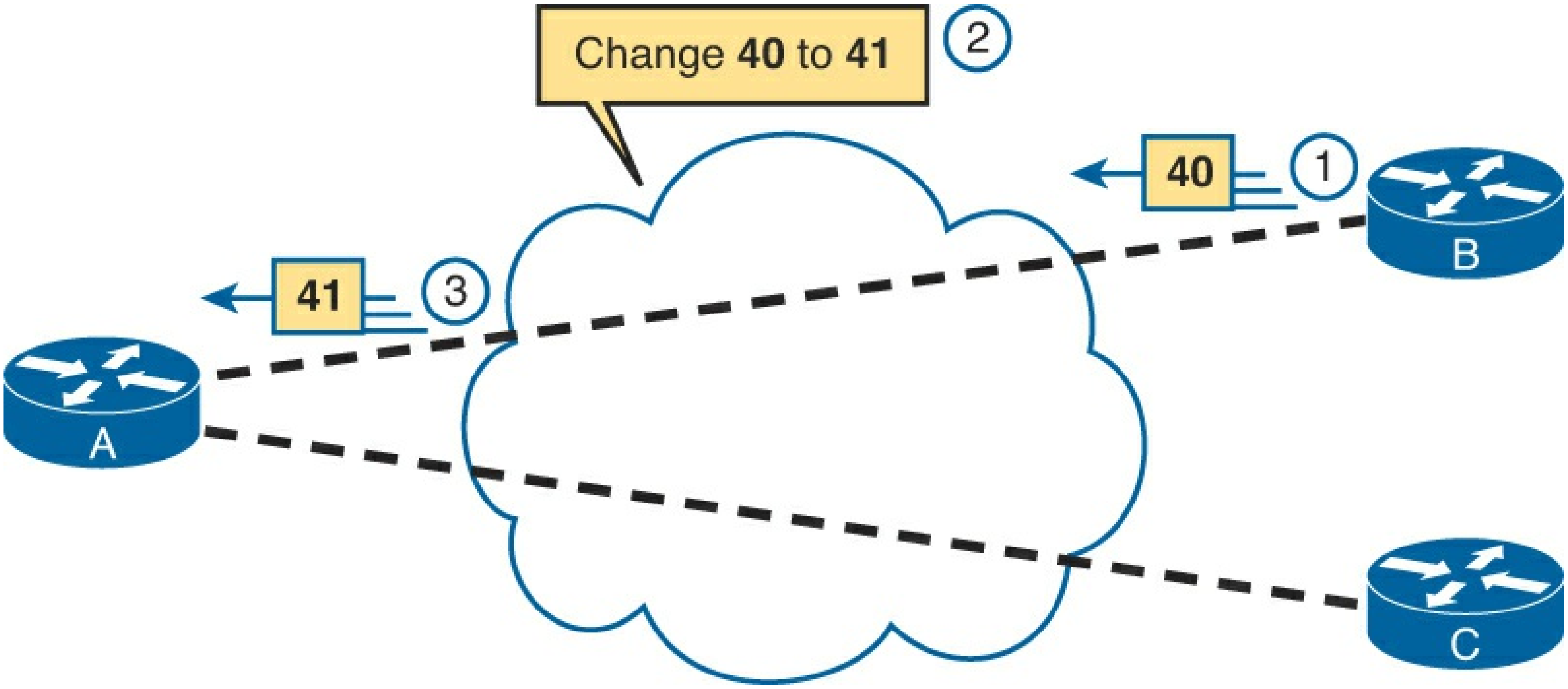


Figure 13-9. Frame Relay Forwarding: Router B to Router A

The same idea happens on each and every PVC. Earlier, Figure 13-7 introduced two PVCs, including an A-to-C PVC, with local DLCIs 42 (A side) and 40 (C side). Figure 13-10 shows the local DLCIs in two different frame flows: first from A to C, and then from C back to A.

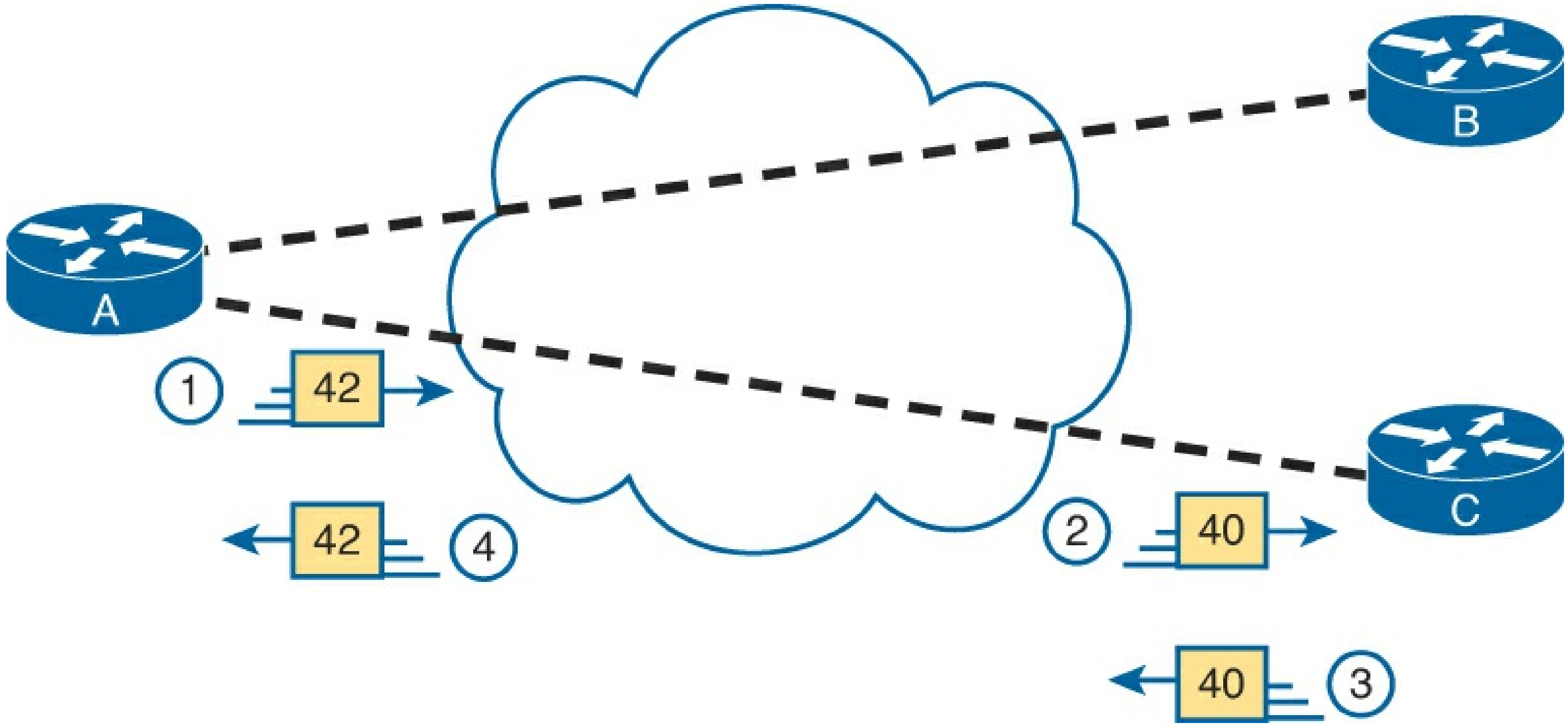


Figure 13-10. Frame Relay Forwarding Between Routers A and C

This figure does not point out the cloud's action of swapping the DLCI values, but the action still takes place. At Step 1, router A forward a frame, DLCI 42. At Step 2, when it exits the cloud toward router C, it has been changed to use DLCI 40, router C's local DLCI for this PVC. Similarly, at Step 3, router C sends a frame, with local DLCI 40. The cloud changes the DLCI to 40, so that when it exits the cloud toward router A at Step 4, the frame lists router A's local DLCI, which is 42.

Network Layer Addressing with Frame Relay

Frame Relay networks have both similarities and differences as compared to LAN and point-to-point WAN links. These differences introduce some additional considerations for passing Layer 3 packets across a Frame Relay network. In particular, Frame Relay gives us three different options for assigning subnets and IP addresses on Frame Relay interfaces:

Key Topic

- One subnet containing all Frame Relay DTEs
- One subnet per VC
- A hybrid of the first two options

This section examines the three main options for IP addressing over Frame Relay.

Frame Relay Layer 3 Addressing: One Subnet Containing All Frame Relay DTEs

Figure 13-11 shows the first alternative, which is to use a single subnet for the Frame Relay network. This figure shows a fully meshed Frame Relay network because the single-subnet option is usually used when a full mesh of VCs exists. In a full mesh, each router has a VC to every other router, meaning that each router can send frames directly to every other router. This more closely resembles how a LAN works. So, a single subnet can be used for all the routers' Frame Relay interfaces, as configured on the routers' serial interfaces. Table 13-4 summarizes the addresses used in Figure 13-11.

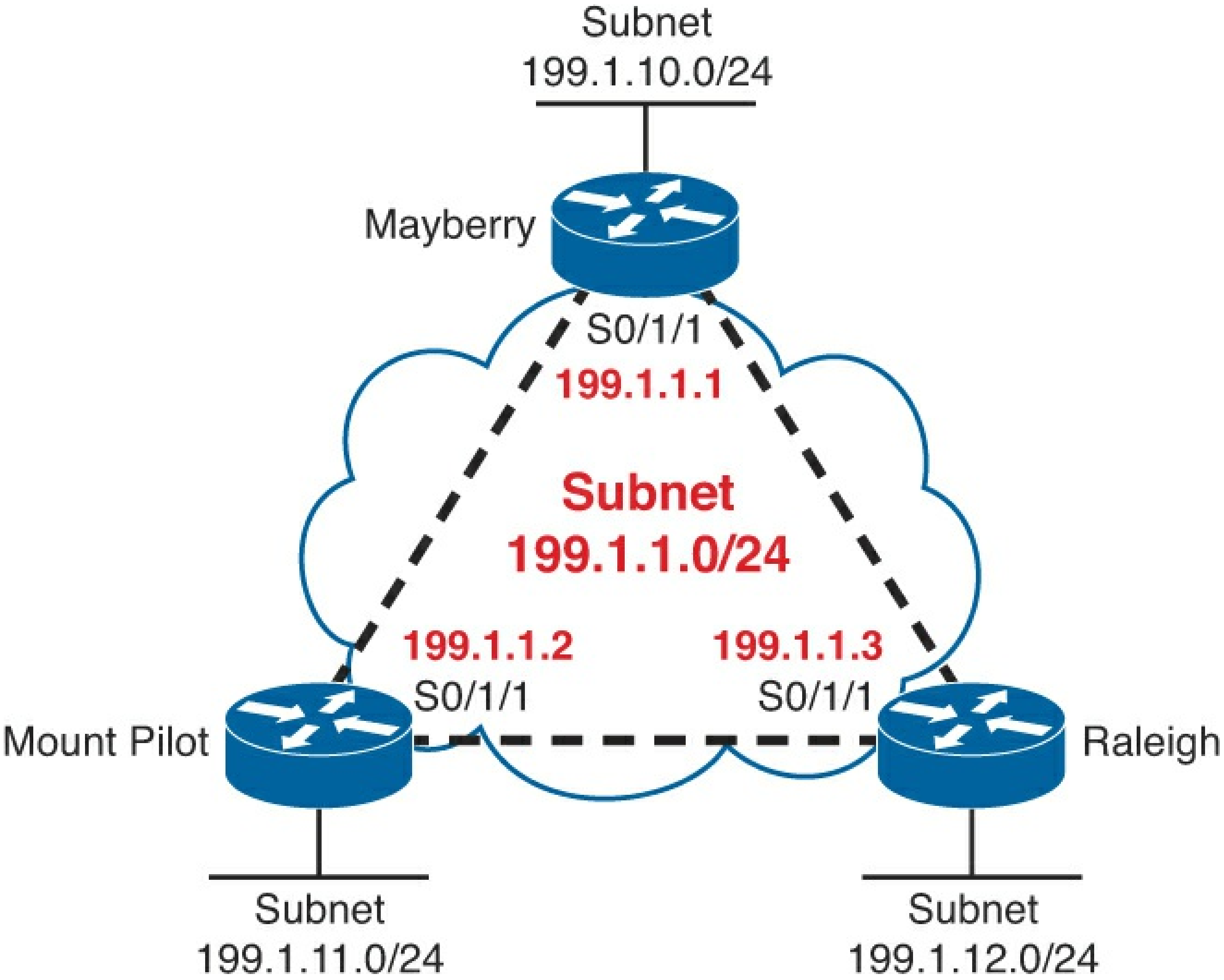

Subnet
199.1.10.0/24
Mayberry
S0/1/1
199.1.1.1
Subnet
199.1.1.0/24
199.1.1.2
S0/1/1
199.1.1.3
S0/1/1
Mount Pilot
Raleigh
Subnet
199.1.11.0/24
Subnet
199.1.12.0/24

Figure 13-11. Full Mesh with IP Addresses

Table 13-4. IP Addresses with No Subinterfaces

Router	IP Address of Frame Relay Interface
Mayberry	199.1.1.1
Mount Pilot	199.1.1.2
Raleigh	199.1.1.3

The single-subnet alternative is straightforward, and it conserves your IP address space. It also looks like what you are used to with LANs, which makes it easier to conceptualize. Unfortunately, most companies build partial-mesh Frame Relay networks, and the single-subnet option has some deficiencies when the network is a partial mesh.

Frame Relay Layer 3 Addressing: One Subnet Per VC

The second IP addressing alternative, having a single subnet for each VC, works better with a partially meshed Frame Relay network, as shown in Figure 13-12. Boston cannot forward frames directly to Charlotte because no VC is defined between the two. This is a more typical Frame Relay network because most organizations with many sites tend to group applications on servers at a few centralized locations and most of the traffic is between each remote site and those servers.

Key Topic

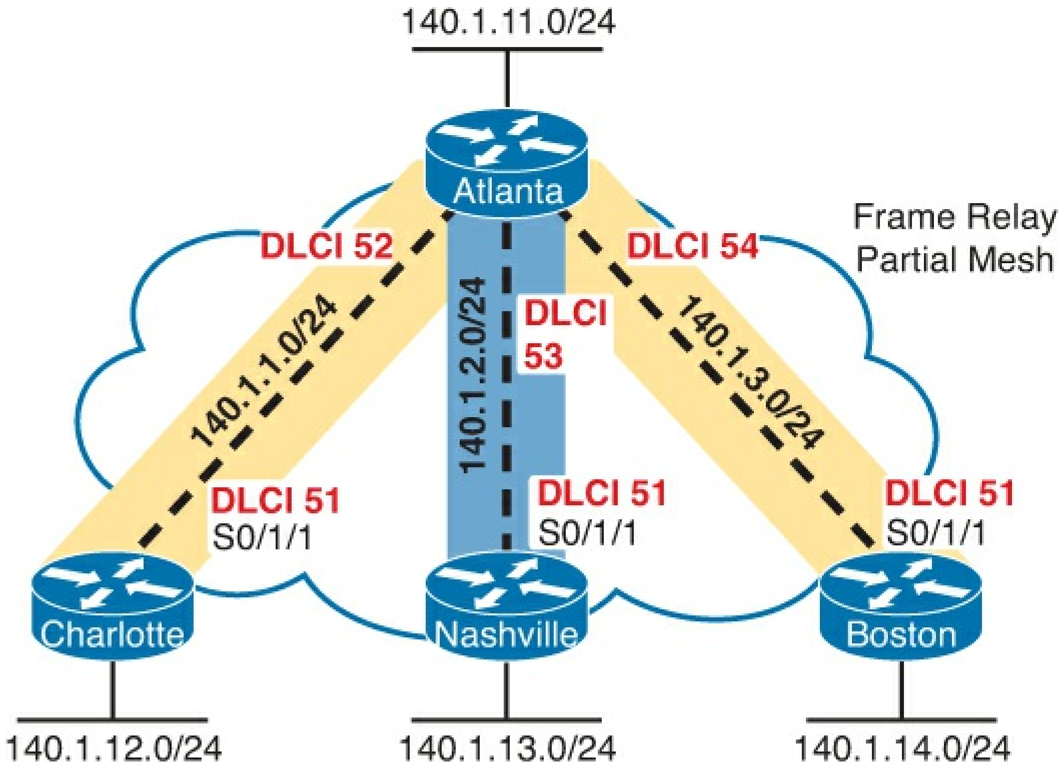


Figure 13-12. Partial Mesh with IP Addresses

The single-subnet-per-VC subnetting design uses the same logic as a set of point-to-point links. Using multiple subnets instead of one larger subnet does waste some IP addresses. However, using a single subnet in the partial-mesh design of Figure 13-12 introduces several problems with routing protocols because not all routers in the subnet can send messages directly to each other. Partial-mesh designs work better with a single-subnet-per-VC approach.

Table 13-5 shows the IP addresses for the partially meshed Frame Relay network shown in Figure 13-12.

Table 13-5. IP Addresses with Point-to-Point Subinterfaces

Router	Subnet	IP Address
Atlanta	140.1.1.0	140.1.1.1
Charlotte	140.1.1.0	140.1.1.2
Atlanta	140.1.2.0	140.1.2.1
Nashville	140.1.2.0	140.1.2.3
Atlanta	140.1.3.0	140.1.3.1
Boston	140.1.3.0	140.1.3.4

Cisco IOS software has a configuration feature called *subinterfaces* that creates a logical subdivision of a physical interface. Subinterfaces allow the Atlanta router to have three IP addresses associated with its serial 0/1/1 physical interface by configuring three separate subinterfaces. A router can treat each subinterface, and the VC associated with it, as if it were a point-to-point serial link. Each of the three subinterfaces of serial 0/1/1 on Atlanta would be assigned a different IP address from Table 13-5 (Example 14-8 in Chapter 14 shows Atlanta's configuration to match the address in Table 13-5, including the subinterfaces of S0/1/1.)

> **Note**
>
> The example uses IP address prefixes of *24 to keep the math simple. In production networks, point-to-point subinterfaces usually use a prefix of* 30 (mask 255.255.255.252) because that allows for only two valid IP addresses—the exact number needed on a point-to-point subinterface. Of course, using different masks in the same network means that your routing protocol must also support VLSM.

Frame Relay Layer 3 Addressing: Hybrid Approach

The third alternative for Layer 3 addressing is a hybrid of the first two alternatives. Consider Figure 13-13, which shows a trio of routers with VCs between each of them, and two other VCs to remote sites.

Two options exist for Layer 3 addressing in this case. The first is to treat each VC as a separate Layer 3 group. In this case, five subnets are needed for the Frame Relay network. However, Routers A, B, and C create a smaller full mesh between each other. This allows Routers A, B, and C to use one subnet. The other two VCs—one between Routers A and D and one between Routers A and E—are treated as two separate Layer 3 groups. The result is a total of three subnets.

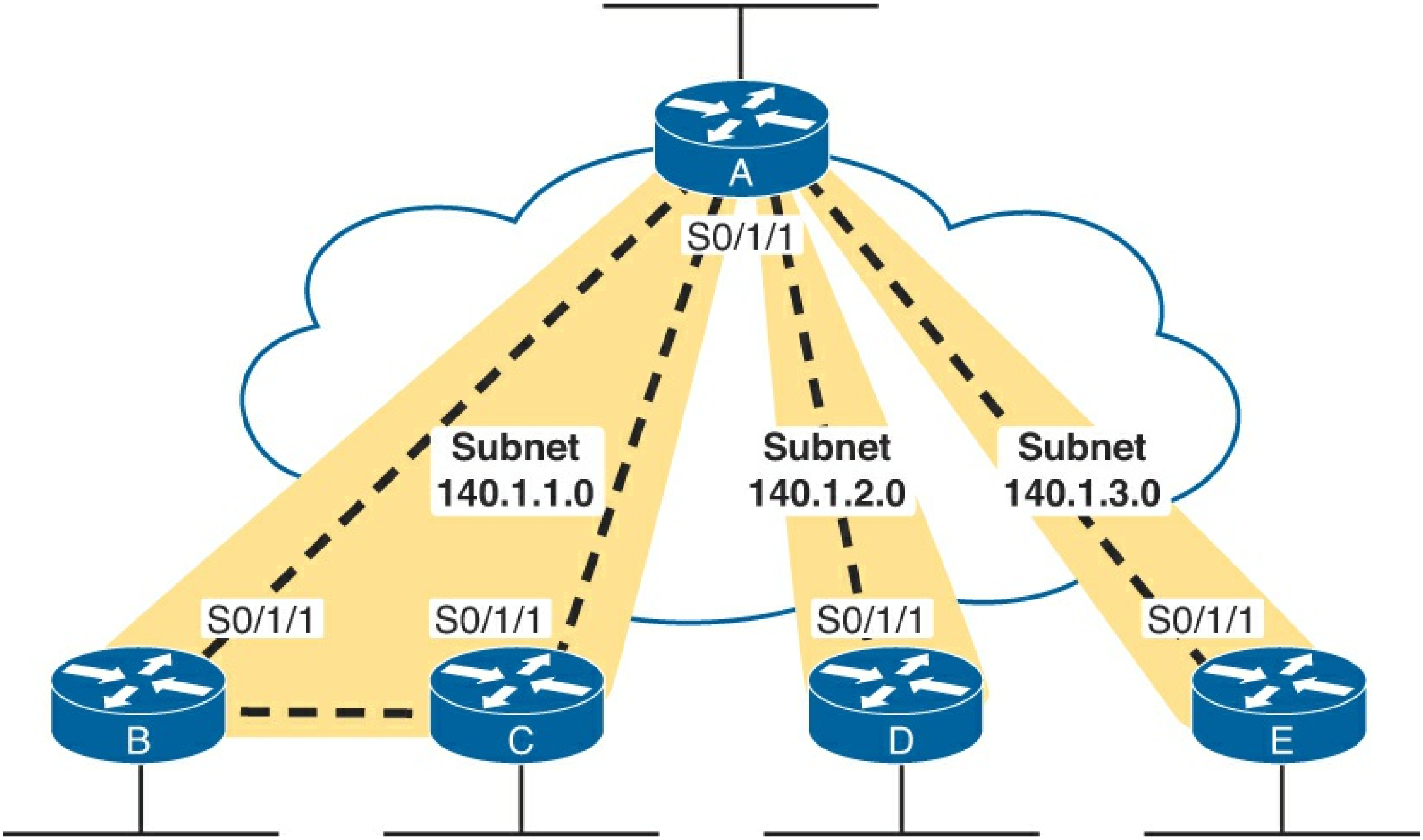


Figure 13-13. Hybrid of Full and Partial Mesh

To accomplish either style of Layer 3 addressing in this third and final case, subinterfaces are used. Point-to-point subinterfaces are used when a single VC is considered to be all that is in the group—for instance, between routers A and D and between routers A and E. Multipoint subinterfaces are used when more than two routers are considered to be in the same group—for instance, with routers A, B, and C.

Multipoint subinterfaces logically terminate more than one VC. In fact, the name *multipoint* implies the function, because more than one remote site can be reached via a VC associated with a multipoint subinterface.

Table 13-6 summarizes the addresses and subinterfaces that are used in Figure 13-13.

Table 13-6. IP Addresses with Point-to-Point and Multipoint Subinterfaces

Router	Subnet	IP Address	Subinterface Type
A	140.1.1.0/24	140.1.1.1	Multipoint
B	140.1.1.0/24	140.1.1.2	Multipoint
C	140.1.1.0/24	140.1.1.3	Multipoint
A	140.1.2.0/24	140.1.2.1	Point-to-point
D	140.1.2.0/24	140.1.2.4	Point-to-point
A	140.1.3.0/24	140.1.3.1	Point-to-point
E	140.1.3.0/24	140.1.3.5	Point-to-point

What will you see in a real network? Most of the time, point-to-point subinterfaces are used with a single subnet per PVC. However, you should understand all options for the CCNA exams.

Note

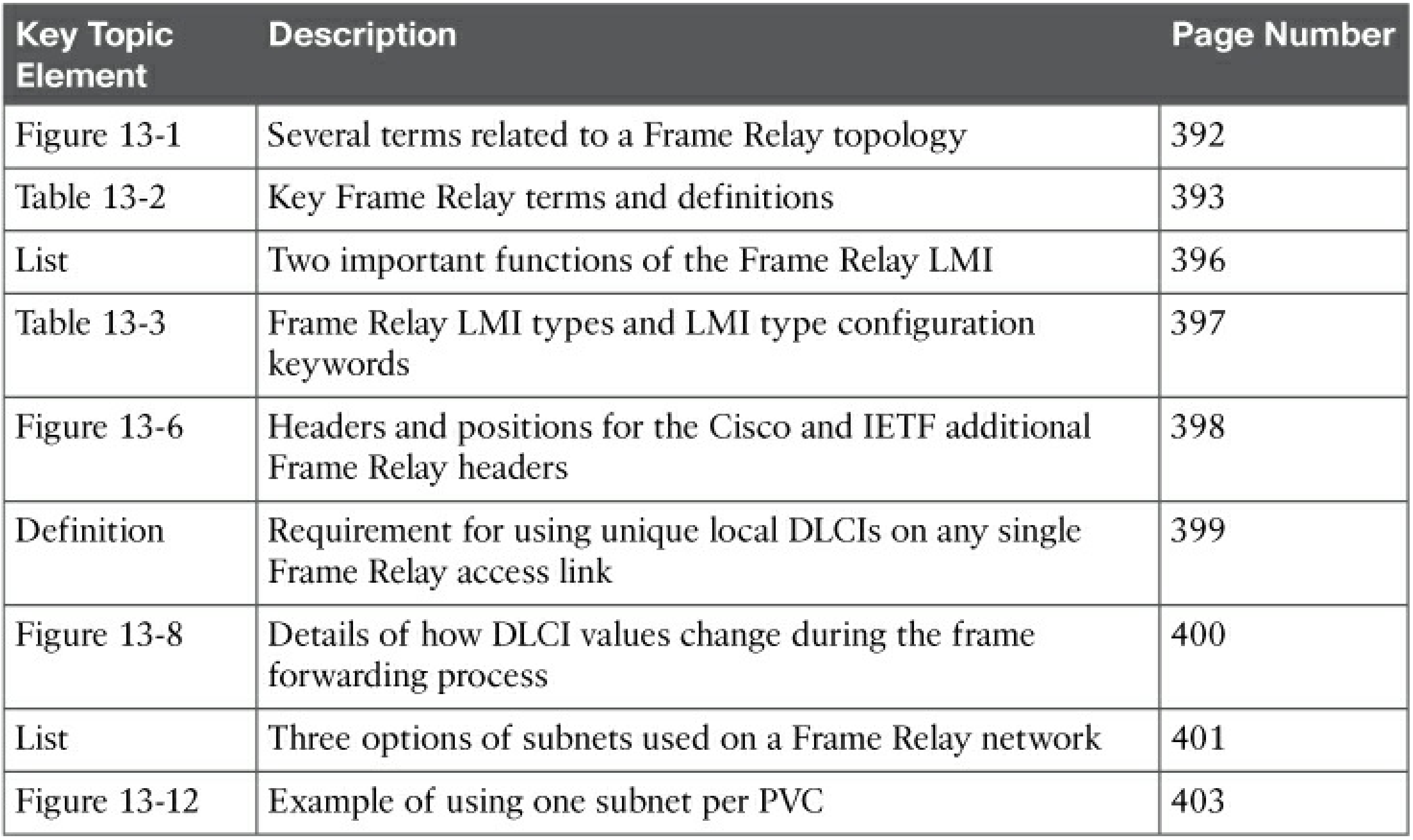
Chapter 14 provides full configurations for all three cases illustrated in Figures 13-11, 13-12, and 13-13.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 13-7 lists these key topics and where each is discussed.

Table 13-7. Key Topics for Chapter 13



Key Topic Element	Description	Page Number
Figure 13-1	Several terms related to a Frame Relay topology	392
Table 13-2	Key Frame Relay terms and definitions	393
List	Two important functions of the Frame Relay LMI	396
Table 13-3	Frame Relay LMI types and LMI type configuration keywords	397
Figure 13-6	Headers and positions for the Cisco and IETF additional Frame Relay headers	398
Definition	Requirement for using unique local DLCIs on any single Frame Relay access link	399
Figure 13-8	Details of how DLCI values change during the frame forwarding process	400
List	Three options of subnets used on a Frame Relay network	401
Figure 13-12	Example of using one subnet per PVC	403

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22 directs you in how to use these terms for late-stage preparation for the exam.

access link
access rate
committed information rate (CIR)
data link connection identifier (DLCI)
Frame Relay DCE
Frame Relay DTE
Local Management Interface (LMI)
nonbroadcast multiaccess (NBMA)
permanent virtual circuit (PVC)

virtual circuit (VC)

Chapter 14. Implementing Frame Relay

This chapter covers the following exam topics:

WAN Technologies

Configure and verify Frame Relay on Cisco routers

Troubleshooting

Troubleshoot and Resolve WAN implementation issues

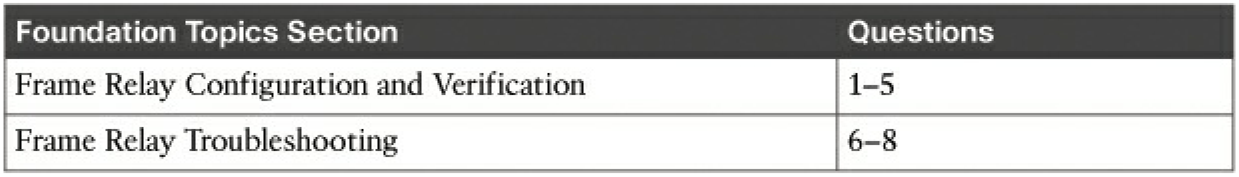
Frame relay

Chapter 13, "Understanding Frame Relay Concepts," introduced and explained the main concepts behind Frame Relay. This chapter shows you how to configure the features on Cisco routers, how to verify that each feature works, and how to troubleshoot problems with forwarding packets over a Frame Relay network.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the Exam Preparation Tasks section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 14-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Frame Relay Configuration and Verification	1–5
Frame Relay Troubleshooting	6–8

1. Imagine two Cisco routers, R1 and R2, using a Frame Relay service. R1 connects to a switch that uses LMI type ANSI T1.617, and R2 connects to a switch that uses ITU Q.933a. What keywords could be used in the R1 and R2 configuration so that the LMIs work correctly?

   a. ansi and **itu**

   b. T1617 and **q933a**

   c. ansi and **q933a**

   d. T1617 and **itu**

   e. Not possible with two different types

2. A company has five sites with routers connected to the same Frame Relay network. VCs have been defined between each pair of routers. Betty, the company president, will fire anyone who configures anything that could just as easily be left as a default. Which of the following configuration commands, configured for the Frame Relay network, would get the engineer fired? (Choose three answers.)

   a. ip address

   b. encapsulation

   c. lmi-type

   d. frame-relay map

   e. frame-relay inverse-arp

3. A company has some routers connected to a Frame Relay network. R1 is a router at a remote site with a single VC back to the company's headquarters. The R1 configuration currently looks like this:

```
interface serial 0/0
ip address 10.1.1.1 255.255.255.0
encapsulation frame-relay
```

   Wilma, the company president, has heard that point-to-point subinterfaces are cool, and she wants you to change the configuration to use a point-to-point subinterface. Which of the following commands do you need to use to migrate the configuration? (Choose two answers.)

   a. no ip address

   b. interface-dlci

   c. no encapsulation

   d. encapsulation frame-relay

   e. frame-relay interface-dlci

4. A company has a Frame Relay network, with a main site router that has ten VCs connecting to the ten remote sites. Wilma (the company president) now thinks that multipoint subinterfaces are even cooler than point-to-point. The current main site router's configuration looks like this:

```
interface serial 0/0
ip address 172.16.1.1 255.255.255.0
encapsulation frame-relay
```

Wilma wants you to change the configuration to use a multipoint subinterface. Which of the following do you need to use to migrate the configuration? (Note: DLCIs 101 through 110 are used for the ten VCs.)

- **a. interface-dlci 101 110**
- **b. interface dlci 101-110**
- **c.** Ten different **interface-dlci** commands
- **d. frame-relay interface-dlci 101 110**
- **e. frame-relay interface dlci 101-110**
- **f.** Ten different **frame-relay interface-dlci** commands

5. Which of the following commands lists the information learned by Inverse ARP?
   - **a. show ip arp**
   - **b. show arp**
   - **c. show inverse arp**
   - **d. show frame-relay inverse-arp**
   - **e. show map**
   - **f. show frame-relay map**
6. Which of the following are Frame Relay PVC status codes that mean that the router can send frames for the associated PVC?
   - **a.** Up
   - **b.** Down
   - **c.** Active
   - **d.** Inactive
   - **e.** Deleted
7. Central site router RC has a VC connecting to ten remote routers (R1 through R10), with RC's local DLCIs being 101 through 110, respectively. RC has grouped DLCIs 107, 108, and 109 into a single multipoint subinterface S0/0.789, whose current status is "up and up." Which of the following must be true? (Choose two answers.)
   - **a.** Serial 0/0 could be in an up/down state.
   - **b.** The PVC with DLCI 108 could be in an inactive state.
   - **c.** The **show frame-relay map** command lists mapping information for all three VCs.
   - **d.** At least one of the three PVCs is in an active or static state.
8. Frame Relay router R1 uses interface S0/0 to connect to a Frame Relay access link. The physical interface is in an up/down state. Which of the following could cause this problem? (Choose two answers.)
   - **a.** The access link has a physical problem and cannot pass bits between the router and switch.
   - **b.** The switch and router are using different LMI types.
   - **c.** The router configuration is missing the **encapsulation frame-relay** command on interface S0/0.
   - **d.** The router received a valid LMI status message that listed some of the DLCIs as inactive.

Answers to the "Do I Know This Already?" quiz:

1 C 2 C, D, and E 3 A and E 4 F 5 F 6 C 7 B and D 8 B and C

Foundation Topics

Frame Relay Configuration and Verification

Frame Relay configuration can be very basic or somewhat detailed, depending on how many default settings can be used. By default, Cisco IOS automatically senses the Local Management Interface (LMI) type and automatically discovers the mapping between DLCI and next-hop IP addresses (using Inverse Address Resolution Protocol [ARP]). If you use all Cisco routers, the default to use Cisco encapsulation works without any additional configuration. If you also design the Frame Relay network to use a single subnet, you can configure the routers to use their physical interfaces without any subinterfaces—making the configuration shorter still. In fact, using as many default settings as possible, the only new configuration command for Frame Relay, as compared to point-to-point WANs, is the **encapsulation frame-relay** command.

Frame Relay questions on CCNA exams can prove difficult for a couple of reasons. First, Frame Relay includes a variety of optional settings that you can configure. Second, for network engineers who already have some experience with Frame Relay, that experience may be with one of the three main options for Frame Relay configuration (physical, multipoint, or point-to-point), but the exams cover all options. So, it is important for the exams that you take the time to look at samples of all the options, which are covered here.

Planning a Frame Relay Configuration

Engineers must do a fair amount of planning before knowing where to start with the configuration. When planning for new sites, you must consider the following items and communicate them to the Frame Relay provider, which in turn has some impact on the routers' Frame Relay configurations:

- Define which physical sites need a Frame Relay access link installed, and define the clock rate (access rate) used on each link.
- Define each VC by identifying the endpoints and setting the committed information rate (CIR).
- Agree to an LMI type (usually dictated by the provider).

The network engineer who plans the Frame Relay configuration must also choose the following setting, independent of any settings of the Frame Relay provider:

- Choose the IP subnetting scheme: one subnet for all virtual circuits (VC), one subnet for each VC, or a subnet for each fully meshed subset.
- Pick whether to assign the IP addresses to physical, multipoint, or point-to-point subinterfaces.
- Choose which VCs need to use IETF encapsulation instead of the default value of cisco. (IETF encapsulation is usually used when one router is not a Cisco router.)

After the planning has been completed, the configuration steps flow directly from the choices made when planning the network. The following list summarizes the configuration steps, mainly as a study tool. (You do not need to memorize the steps; the list is just a tool to help organize your thinking about the configuration.)

Key Topic

Step 1. Configure the physical interface to use Frame Relay encapsulation (**encapsulation frame-relay** interface subcommand).

Step 2. Configure an IP address on the interface or subinterface (**ip address** subcommand).

Step 3. (Optional) Manually set the LMI type on each physical serial interface (**frame-relay lmi-type** interface subcommand).

Step 4. (Optional) Change from the default encapsulation of **cisco,** to **ietf,** by doing the following:

  A. For all VCs on the interface, add the **ietf** keyword to the **encapsulation frame-relay** interface subcommand.

  B. For a single VC, add the **ietf** keyword to the **frame-relay interface-dlci** interface subcommand (point-to-point subinterfaces only) or to the **frame-relay map** command.

Step 5. (Optional) If you aren't using the (default) Inverse ARP to map the DLCI to the next-hop router's IP address, define static mapping using the **frame-relay map ip** *ip-address dlci* **broadcast** subinterface subcommand.

Step 6. On subinterfaces, associate one DLCI (point-to-point) or multiple DLCIs (multipoint) with the subinterface in one of two ways:

  A. Using the **frame-relay interface-dlci** *dlci* subinterface subcommand

  B. As a side effect of static mapping, using the **frame-relay map ip** *ip-address dlci* **broadcast** subinterface subcommand

The rest of this section shows examples of all these configuration steps, along with some discussion about how to verify that the Frame Relay network is working correctly.

Configuring Using Physical Interfaces and One IP Subnet

The first example shows the briefest possible Frame Relay configuration, one that uses just the first two steps of the configuration checklist in this chapter. The design for the first example includes the following choices:

- Install an access link into three routers.
- Create a full mesh of PVCs.
- Use a single subnet (Class C network 199.1.1.0 in this example) in the Frame Relay network.
- Configaure the routers using their physical interfaces.
- Take the default settings for LMI, Inverse ARP, and encapsulation.

Examples 14-1, 14-2, and 14-3 show the configuration for the network shown in Figure 14-1.

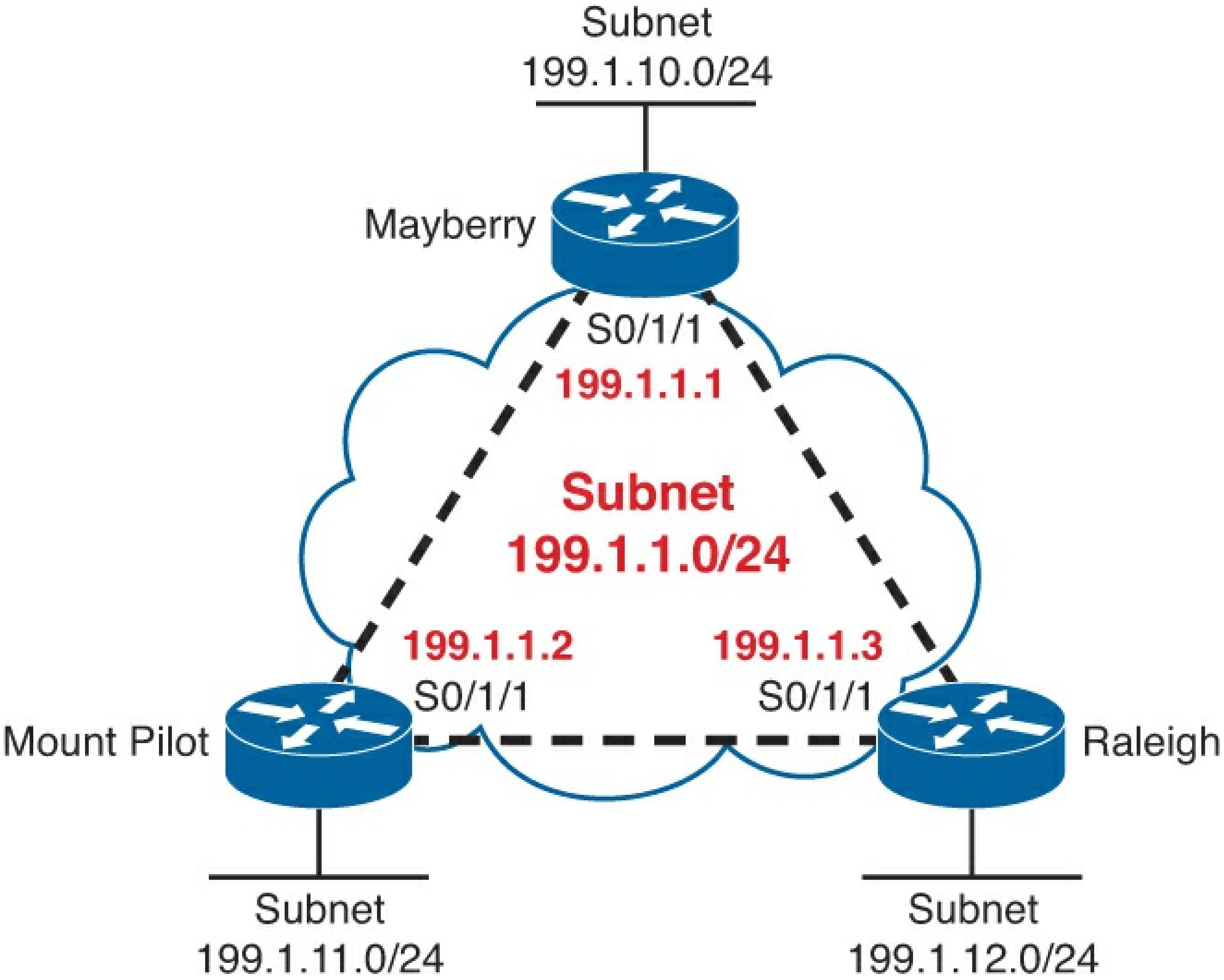

Subnet
199.1.10.0/24
Mayberry
S0/1/1
199.1.1.1
Subnet
199.1.1.0/24
199.1.1.2
S0/1/1
199.1.1.3
S0/1/1
Mount Pilot
Raleigh
Subnet
199.1.11.0/24
Subnet
199.1.12.0/24

Figure 14-1. Full Mesh with IP Addresses

Example 14-1. Mayberry Configuration

[Click here to view code image](#)

```
interface serial0/1/1
encapsulation frame-relay
ip address 199.1.1.1 255.255.255.0
!
interface gigabitethernet 0/0
ip address 199.1.10.1 255.255.255.0
!
router eigrp 1
network 199.1.1.0
network 199.1.10.0
```

Example 14-2. Mount Pilot Configuration

[Click here to view code image](#)

```
interface serial0/1/1
encapsulation frame-relay
ip address 199.1.1.2 255.255.255.0
!
interface gigabitethernet 0/0
ip address 199.1.11.2 255.255.255.0
!
router eigrp 1
network 199.1.1.0
network 199.1.11.0
```

Example 14-3. Raleigh Configuration

Click here to view code image

```
interface serial0/1/1
encapsulation frame-relay
ip address 199.1.1.3 255.255.255.0
!
interface gigabitethernet 0/0
ip address 199.1.12.3 255.255.255.0
!
router eigrp 1
network 199.1.1.0
network 199.1.12.0
```

The configuration is simple in comparison with the protocol concepts. The **encapsulation frame-relay** command tells the routers to use Frame Relay data link protocols instead of the default, which is High-Level Data Link Control (HDLC). Note that the IP addresses on the three routers' serial interfaces are all in the same Class C network. Also, this simple configuration takes advantage of the following IOS default settings:

- The LMI type is automatically sensed.
- The (default) encapsulation is Cisco.
- PVC DLCIs are learned via LMI status messages.
- Inverse ARP is enabled (by default) and is triggered when a router receives an LMI status message declaring that the VCs are up is received.

Configuring the Encapsulation and LMI

In many cases, using the defaults as listed with the first example works just fine. However, for the purpose of showing an alternative configuration, suppose that the following requirements were added to the requirements surrounding the design in Figure 14-1:

- The Raleigh router requires IETF encapsulation on both VCs.
- Mayberry's LMI type should be ANSI, and LMI autosense should not be used.

To change these defaults, the steps outlined as optional configuration Steps 3 and 4 in the configuration checklist should be used. Examples 14-4 and 14-5 show the changes that would be made to Mayberry and Raleigh.

Example 14-4. Mayberry Configuration with New Requirements

Click here to view code image

```
interface serial0/1/1
encapsulation frame-relay
frame-relay lmi-type ansi
frame-relay map ip 199.1.1.3 53 ietf
ip address 199.1.1.1 255.255.255.0
! rest of configuration unchanged from Example 14-1.
```

Example 14-5. Raleigh Configuration with New Requirements

Click here to view code image

```
interface serial0/1/1
encapsulation frame-relay ietf
ip address 199.1.1.3 255.255.255.0

! rest of configuration unchanged from Example 14-3.
```

These configurations differ from the previous ones (in Examples 14-1 and 14-3) in two ways. First, Raleigh changed its encapsulation for both its PVCs with the **ietf** keyword on the **encapsulation** command. This keyword applies to all VCs on the interface. However, Mayberry cannot change its encapsulation in the same way, because only one of the two VCs terminating in Mayberry needs to use IETF encapsulation, and the other needs to use Cisco encapsulation. So, Mayberry is forced to code the **frame-relay map** command, referencing the DLCI for the VC to Raleigh, with the **ietf** keyword. With that command, you can change the encapsulation setting per VC, as opposed to the configuration on Raleigh, which changes the encapsulation for all VCs.

The second major change is the LMI configuration. The LMI configuration in Mayberry would be fine without any changes because the default use of LMI autosense would recognize ANSI as the LMI type. However, by coding the **frame-relay lmi-type ansi** interface subcommand, Mayberry must use ANSI, because this command not only sets the LMI type, but it also disables autosensing of the LMI type.

> **Note**
>
> The LMI setting is a per-physical-interface setting, even if subinterfaces are used, so the **frame-relay lmi-type** command is always a subcommand under the physical interface.

Mount Pilot needs to configure a **frame-relay map** command with the **ietf** keyword for its VC to Raleigh, just like Mayberry. This change is not shown in the examples.

Frame Relay Address Mapping

Figure 14-1 does not even bother listing the DLCIs used for the VCs. The earlier configurations work as stated, and frankly, if you never knew the DLCIs, this network would work! However, for the exams, and for real networking jobs, engineers need to know the DLCIs, and the process of Frame Relay mapping.

Frame Relay mapping matches a next-hop IP address that sits on the Frame Relay network with the right DLCI used to send frames to that next-hop device, with the same goal as ARP on a LAN. Figure 14-2 shows the same network, this time with local DLCI values shown.

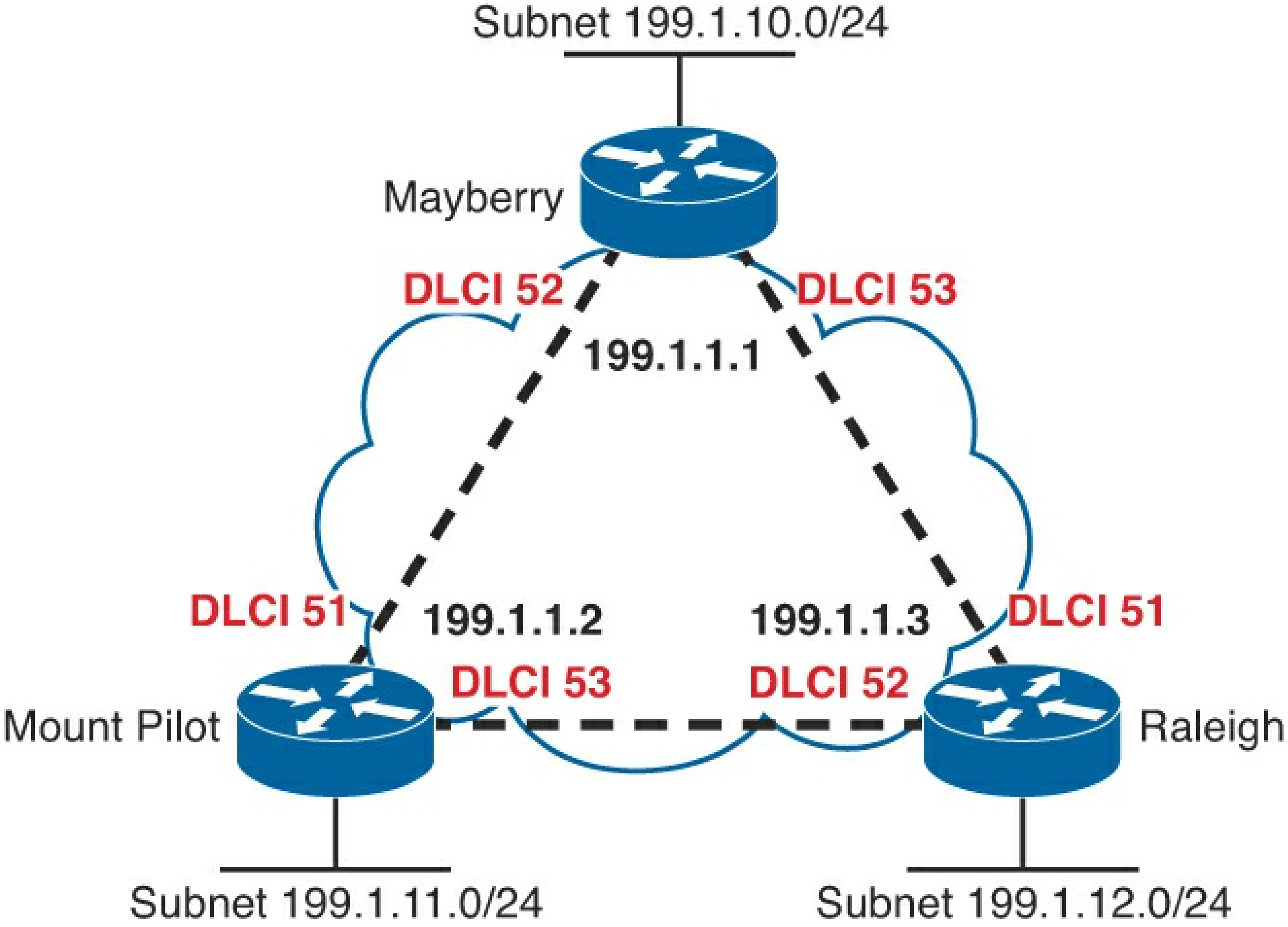


Figure 14-2. Full Mesh with Local DLCIs Shown

Frame Relay “mapping” creates a correlation between a Layer 3 address and its corresponding Layer 2 address. The concept is similar to the ARP cache for LAN interfaces. For example, the IP Address Resolution Protocol (ARP) cache used on LANs is an example of Layer 3-to-Layer 2 address mapping. With IP ARP, you know the IP address of another device on the same LAN, but not the MAC address; when the ARP completes, you know another device’s LAN (Layer 2) address. Similarly, routers that use Frame Relay need a mapping between a router’s Layer 3 address and the DLCI used to reach that other router.

This section discusses the basics of why mapping is needed for LAN connections and Frame Relay, with a focus on Frame Relay. Here’s a more general definition of mapping:

Key Topic

> The information that correlates to the next-hop router’s Layer 3 address and the Layer 2 address used to reach it is called mapping. Mapping is needed on multiaccess networks.

Thinking about routing helps make the need for mapping more apparent. For example, consider a packet that enters

Mayberry's LAN interface destined for network 199.1.11.0/24, the Class C network off Mount Pilot's LAN interface. As shown in Figure 14-3, the router goes through normal routing steps, removing the packet from between the Ethernet header and trailer, choosing to route the packet out Mayberry's S0/1/1 interface to Mount Pilot next, and so on. But what DLCI should Mayberry put into the new Frame Relay header?

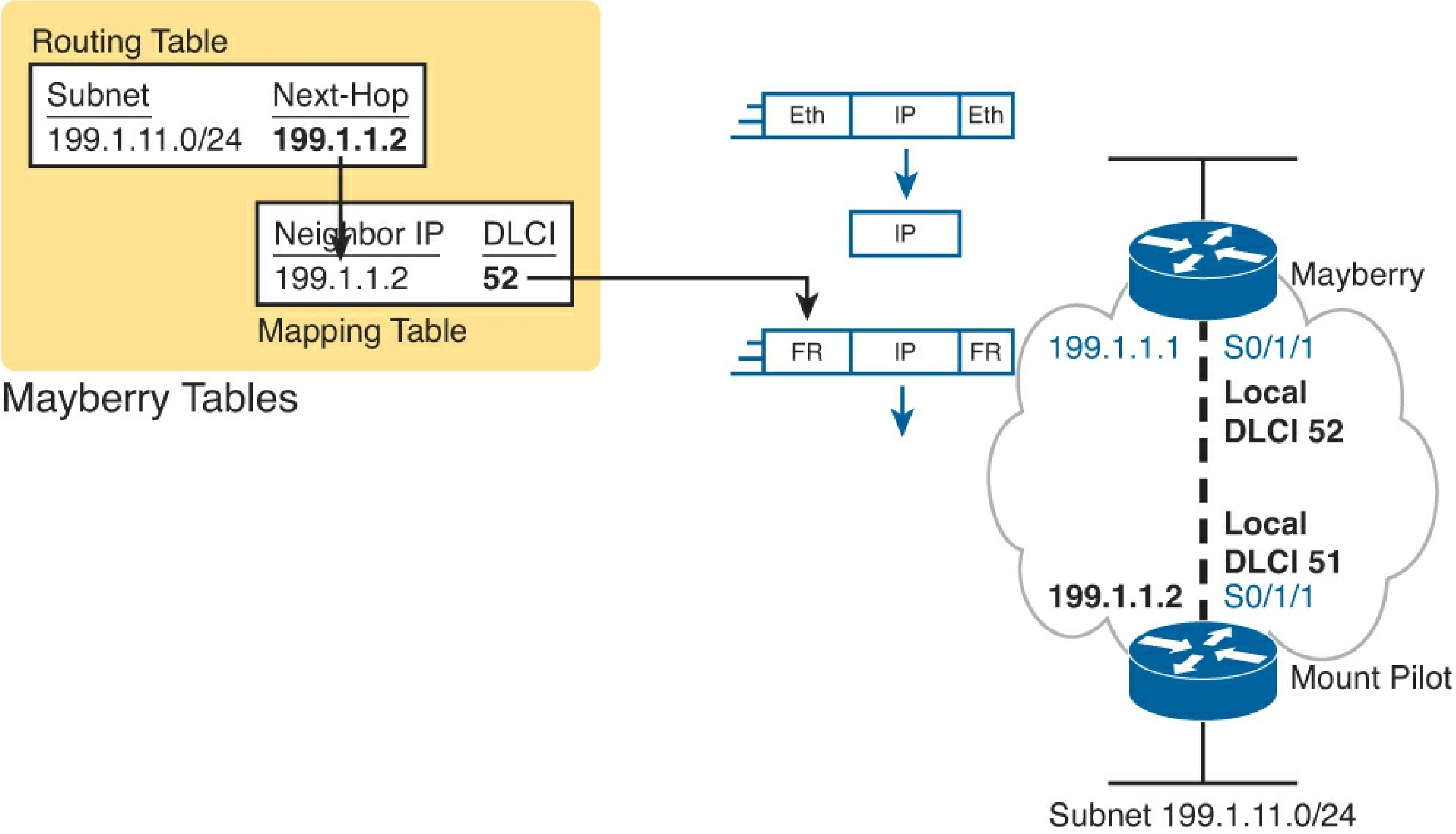


Figure 14-3. Logic on Mayberry to Choose the Correct DLCI

The left side of the figure shows the tables Mayberry uses to choose the right DLCI. First, Mayberry looks at the route it uses to forward the packet, finding the next-hop router IP address. Then, the Frame Relay Mapping table lists that same next-hop router IP address, along with the DLCI used to send frames to that address (the equivalent of an ARP table). Mayberry then puts that DLCI (52, Mayberry's local DLCI for the PVC connected to Mount Pilot) into the Frame Relay header.

Interestingly, just like ARP happens behind the scenes, without being enabled, Frame Relay creates the address mappings behind the scene. Example 14-6 puts the pieces together, matching Figure 14-3. The example lists the routing table, the PVCs (including DLCIs), and the Frame Relay mapping table, all on Mayberry.

Example 14-6. show **Commands on Mayberry, Showing the Need for Mapping**

Click here to view code image

```
Mayberry# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
E1 - OSPF external type 1, E2 - OSPF external type 2
i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
ia - IS-IS inter area, * - candidate default, U - per-user static route
o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
+ - replicated route, % - next hop override

Gateway of last resort is not set

199.1.1.0/24 is variably subnetted, 2 subnets, 2 masks
C 199.1.1.0/24 is directly connected, Serial0/1/1
L 199.1.1.1/32 is directly connected, Serial0/1/1
199.1.10.0/24 is variably subnetted, 2 subnets, 2 masks
C 199.1.10.0/24 is directly connected, GigabitEthernet0/0
L 199.1.10.1/32 is directly connected, GigabitEthernet0/0
D 199.1.11.0/24 [90/2172416] via 199.1.1.2, 00:00:03, Serial0/1/1
D 199.1.12.0/24 [90/2172416] via 199.1.1.3, 00:19:14, Serial0/1/1
```

```
Mayberry# show frame-relay pvc

PVC Statistics for interface Serial0/1/1 (Frame Relay DTE)

Active Inactive Deleted Static
Local 2 0 0 0
Switched 0 0 0 0
Unused 0 0 0 0

DLCI = 52, DLCI USAGE = LOCAL, PVC STATUS = ACTIVE, INTERFACE = Serial0/1/1

input pkts 37 output pkts 39 in bytes 2542
out bytes 2752 dropped pkts 0 in pkts dropped 0
out pkts dropped 0 out bytes dropped 0
in FECN pkts 0 in BECN pkts 0 out FECN pkts 0
out BECN pkts 0 in DE pkts 0 out DE pkts 0
out bcast pkts 26 out bcast bytes 1664
5 minute input rate 0 bits/sec, 0 packets/sec
5 minute output rate 0 bits/sec, 0 packets/sec
pvc create time 00:20:02, last time pvc status changed 00:20:02

DLCI = 53, DLCI USAGE = LOCAL, PVC STATUS = ACTIVE, INTERFACE = Serial0/1/1

input pkts 37 output pkts 37 in bytes 2618
out bytes 2746 dropped pkts 0 in pkts dropped 0
out pkts dropped 0 out bytes dropped 0
in FECN pkts 0 in BECN pkts 0 out FECN pkts 0
out BECN pkts 0 in DE pkts 0 out DE pkts 0
out bcast pkts 25 out bcast bytes 1630
5 minute input rate 0 bits/sec, 0 packets/sec
5 minute output rate 0 bits/sec, 0 packets/sec
pvc create time 00:20:02, last time pvc status changed 00:20:02

Mayberry# show frame-relay map
Serial0/1/1 (up): ip 199.1.1.2 dlci 52(0x34,0xC40), dynamic,
broadcast,, status defined, active
Serial0/1/1 (up): ip 199.1.1.3 dlci 53(0x35,0xC50), dynamic,
broadcast,, status defined, active
```

The example highlights all the related information on Mayberry for sending packets to network 199.1.11.0/24 off Mount Pilot. Mayberry's route to 199.1.11.0 refers to outgoing interface serial 0/1/1 and to 199.1.1.2 as the next-hop address. The **show frame-relay pvc** command lists two DLCIs, 52 and 53, and both are active. How does Mayberry know the DLCIs? Well, the LMI status messages tell Mayberry about the VCs, the associated DLCIs, and the status (active).

Which DLCI should Mayberry use to forward the packet? The **show frame-relay map** command output holds the answer. Notice the highlighted phrase "ip 199.1.1.2 dlci 52" in the output. Somehow, Mayberry has mapped 199.1.1.2, which is the next-hop address in the route, to the correct local DLCI, which is 52. So, Mayberry knows to use local DLCI 52 to reach next-hop IP address 199.1.1.2.

Mayberry can use two methods to build the mapping shown in Example 14-6. One uses a statically configured mapping, and the other uses a dynamic process called *Inverse ARP*. The next two small sections explain the details of each of these options.

Inverse ARP

Inverse ARP dynamically creates a mapping between the Layer 3 address (for example, the IP address) and the Layer 2 address (the local DLCI). The end result of Inverse ARP is the same as IP ARP on a LAN: The router builds a mapping between a neighboring Layer 3 address and the corresponding Layer 2 address. However, the process used by Inverse ARP differs for ARP on a LAN. After the VC is up, each router announces its network layer address by sending an Inverse ARP message over that VC. Figure 14-4 shows how this works.

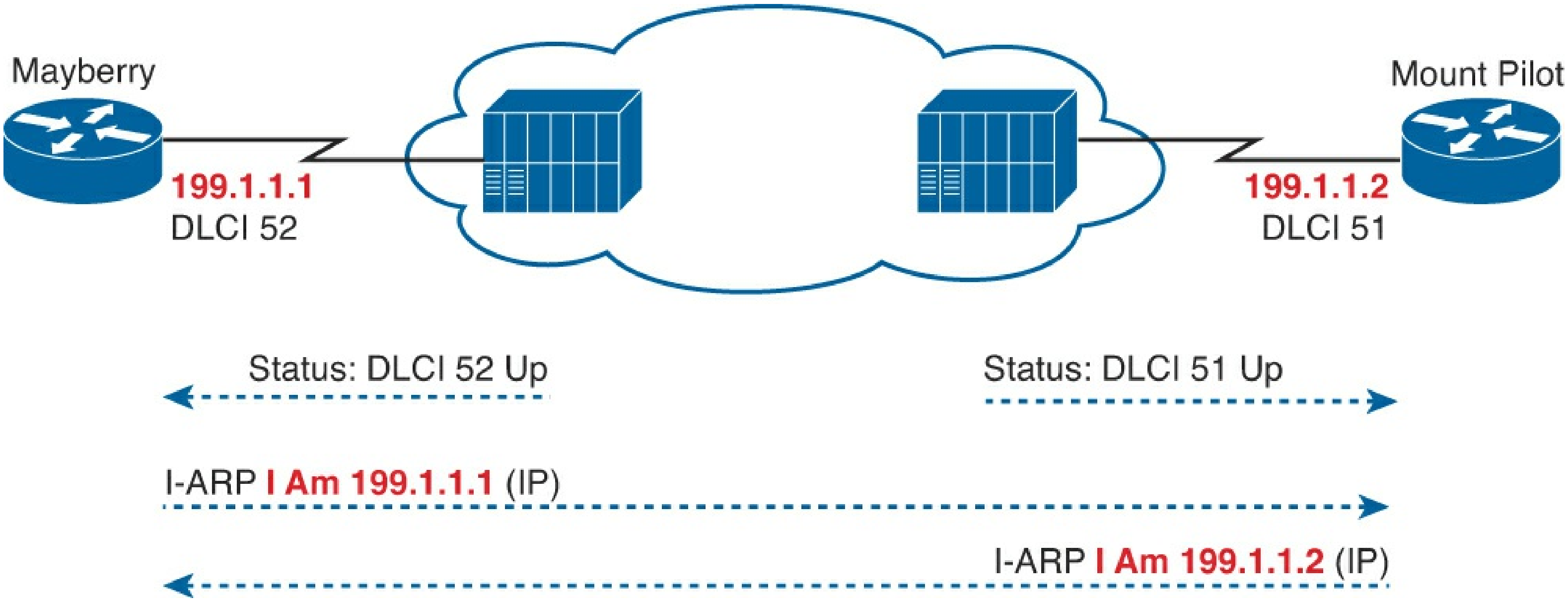


Figure 14-4. Inverse ARP Process

As shown in Figure 14-4, Inverse ARP announces its Layer 3 addresses as soon as the LMI signals that the PVCs are up. Inverse ARP starts by learning the DLCI data link layer address (via LMI messages), and then it announces its own Layer 3 addresses that use that VC. Inverse ARP is enabled by default.

In Example 14-6, Mayberry shows two different entries in the **show frame-relay map** command output. Mayberry uses Inverse ARP to learn that DLCI 52 is mapped to next-hop IP address 199.1.1.2, and that DLCI 53 is mapped to next-hop IP address 199.1.1.3. Interestingly, Mayberry learns this information by receiving an Inverse ARP from Mount Pilot and Raleigh, respectively.

The Inverse ARP process has a few subtle turns of how it works. First, Inverse ARP messages announce a router's IP address, with the frame flowing over a PVC. The receiving router learns the IP address in the message, and it notes the DLCI of the InARP frame. For example, based on Figure 14-4:

- Mayberry sends an InARP with 199.1.1.1; Mount Pilot receives the InARP with DLCI 51 in the header, so Mount Pilot's mapping lists 199.1.1.1 and DLCI 51.
- Mount Pilot sends an InARP with 199.1.1.2; Mayberry receive the InARP with DLCI 52 in the header, so Mayberry's mapping lists 199.1.1.2 and DLCI 52.

Static Frame Relay Mapping

You can statically configure the same mapping information instead of using Inverse ARP. In a production network, you probably would just go ahead and use Inverse ARP. For the exams, you need to know how to configure the static **map** command statements. Example 14-7 lists the static Frame Relay map for the three routers shown in Figure 14-2, along with the configuration used to disable Inverse ARP.

Example 14-7. frame-relay map **Commands**

Click here to view code image

```
Mayberry
interface serial 0/0/0
no frame-relay inverse-arp
frame-relay map ip 199.1.1.2 52 broadcast
frame-relay map ip 199.1.1.3 53 broadcast
```

```
Mount Pilot
interface serial 0/0/0
no frame-relay inverse-arp
frame-relay map ip 199.1.1.1 51 broadcast
frame-relay map ip 199.1.1.3 53 broadcast
```

```
Raleigh
interface serial 0/0/0
no frame-relay inverse-arp
frame-relay map ip 199.1.1.1 51 broadcast
frame-relay map ip 199.1.1.2 52 broadcast
```

As an example to better understand the meaning of the **frame-relay map** command, consider the command on Mayberry referencing 199.1.1.2. The command sits on Mayberry, so it adds a mapping entry in Mayberry. The command tells Mayberry that when Mayberry sends a packet to 199.1.1.2 (Mount Pilot), Mayberry must use DLCI 52. Mayberry's **frame-relay map** statement correlates Mount Pilot's IP address, 199.1.1.2, to the local DLCI used to reach Mount Pilot—namely, DLCI 52.

As another example, consider Mount Pilot's **frame-relay map ip 199.1.1.1 51 broadcast** command. This command creates a mapping entry for Mount Pilot, so when it sends a packet to 199.1.1.1 (Mayberry), Mount Pilot uses DLCI 51.

Mapping is needed for each next-hop Layer 3 address for each Layer 3 protocol being routed. Even with a network this small, the configuration process can be laborious.

> **Note**
>
> The **broadcast** keyword on the **frame-relay map** command is required when the router needs to send broadcasts or multicasts to the neighboring router—for example, to support routing protocol messages such as Hellos.

Configuring Point-to-Point Subinterfaces

The second sample network, based on the environment shown in Figure 14-5, uses point-to-point subinterfaces. Point-to-point subinterfaces work well when the subnetting design calls for one subnet for each PVC. Examples 14-8 through 14-11 show the configuration for this sample network, with all four routers using only point-to-point subinterfaces. Pay close attention to the command prompts Example 14-8, because they change when you configure subinterfaces.

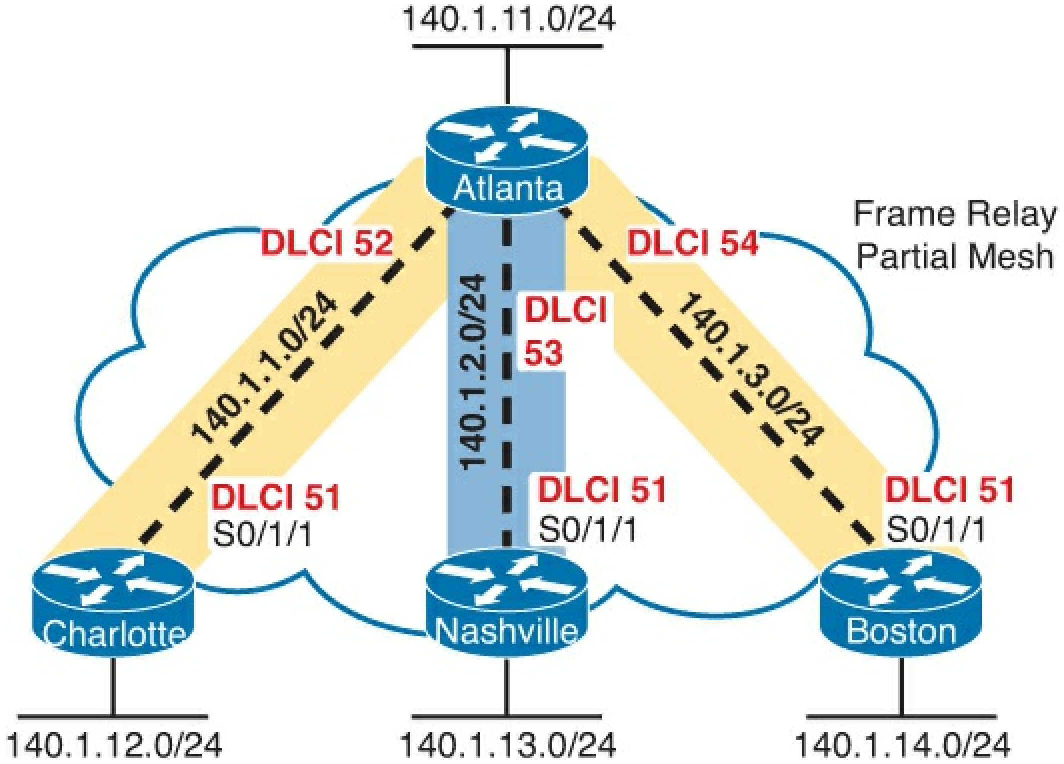


Figure 14-5. Partial Mesh with Subnets and Local DLCIs

Example 14-8. Atlanta Configuration

Click here to view code image

```
Atlanta(config)# interface serial0/1/1
Atlanta(config-if)# encapsulation frame-relay

Atlanta(config-if)# interface serial 0/1/1.1 point-to-point
Atlanta(config-subif)# ip address 140.1.1.1 255.255.255.0
Atlanta(config-subif)# frame-relay interface-dlci 52


Atlanta(config-fr-dlci)# interface serial 0/1/1.2 point-to-point
Atlanta(config-subif)# ip address 140.1.2.1 255.255.255.0
Atlanta(config-subif)# frame-relay interface-dlci 53


Atlanta(config-fr-dlci)# interface serial 0/1/1.3 point-to-point
Atlanta(config-subif)# ip address 140.1.3.1 255.255.255.0
Atlanta(config-subif)# frame-relay interface-dlci 54
Atlanta(config-fr-dlci)# interface gigabitethernet 0/0
Atlanta(config-if)# ip address 140.1.11.1 255.255.255.0
```

Example 14-9. Charlotte Configuration

Click here to view code image

```
interface serial0/1/1
encapsulation frame-relay
!
interface serial 0/1/1.1 point-to-point
ip address 140.1.1.2 255.255.255.0
frame-relay interface-dlci 51
!
interface gigabitethernet 0/0
ip address 140.1.12.2 255.255.255.0
```

Example 14-10. Nashville Configuration

Click here to view code image

```
interface serial0/1/1
encapsulation frame-relay
!
interface serial 0/1/1.2 point-to-point
ip address 140.1.2.3 255.255.255.0
frame-relay interface-dlci 51
!
interface gigabitethernet 0/0
ip address 140.1.13.3 255.255.255.0
```

Example 14-11. Boston Configuration

Click here to view code image

```
interface serial0/1/1
encapsulation frame-relay
!
interface serial 0/1/1.3 point-to-point
ip address 140.1.3.4 255.255.255.0
frame-relay interface-dlci 51
!
interface gigabitethernet 0/0
ip address 140.1.14.4 255.255.255.0
```

Again, defaults abound in this configuration, but some defaults are different than when you're configuring on the physical interface. The LMI type is autosensed, and Cisco encapsulation is used, which is just like the fully meshed examples. Inverse ARP is not really needed on point-to-point subinterfaces, but it is enabled by default in case the router on the other end of the VC needs to use Inverse ARP, as explained later in this section.

Two new commands create the configuration required with point-to-point subinterfaces. First, the **interface serial 0/1/1.1 point-to-point** command creates logical subinterface number 1 under physical interface serial 0/1/1. This command also defines the subinterface as a point-to-point subinterface instead of point-to-multipoint. Then, the configuration must associate one PVC with the subinterface; the **frame-relay interface-dlci** subinterface subcommand tells the router which single local DLCI is associated with that subinterface.

An example of how the **frame-relay interface-dlci** command works can help. Consider router Atlanta in Figure 14-5. Atlanta receives LMI messages on serial 0/01/1 stating that three PVCs, with local DLCIs 52, 53, and 54, are up. Which PVC goes with which subinterface? Cisco IOS software needs to associate the correct PVC with the correct subinterface. This is accomplished with the **frame-relay interface-dlci** command.

Take a moment to work through all the subinterface configuration and **frame-relay interface-dlci** configuration in Example 14-8 through 14-11, and compare it to the DLCIs and IP subnets listed in Figure 14-5. Note that in each case the local DLCI configured on the **frame-relay interface-dlci** command corresponds to the subnet (based on the **ip address** command).

Before leaving the point-to-point configuration, note that the subinterface numbers do not have to match on the router on the other end of the PVC. In this example, I just numbered the subinterfaces to be easier to remember. In real life, it is useful to encode some information about your network numbering scheme into the subinterface number.

For example, a company might encode part of the carrier's circuit ID in the subinterface number so that the operations staff could find the correct information to tell the telco when troubleshooting the link. Many sites use the DLCI as the subinterface number. Of course, useful troubleshooting information, such as the DLCI, the name of the router on the other end of the VC, and so on, could be configured as text with the **description** command as well. In any case, there are no requirements for matching subinterface numbers. This example just matches the subinterface number to the third octet of the IP address.

Verifying Point-to-Point Frame Relay

Example 14-12 shows the output from the most popular Cisco IOS software Frame Relay EXEC commands for monitoring Frame Relay as issued on router Atlanta.

Example 14-12. Output from EXEC Commands on Atlanta

Click here to view code image

```
Atlanta# show frame-relay pvc

PVC Statistics for interface Serial0/1/1 (Frame Relay DTE)

Active Inactive Deleted Static
Local 2 0 0 0
Switched 0 0 0 0
Unused 1 0 0 0

DLCI = 52, DLCI USAGE = LOCAL, PVC STATUS = ACTIVE, INTERFACE = Serial0/1/1

input pkts 80 output pkts 76 in bytes 5940
out bytes 5594 dropped pkts 0 in pkts dropped 0
out pkts dropped 0 out bytes dropped 0
in FECN pkts 0 in BECN pkts 0 out FECN pkts 0
out BECN pkts 0 in DE pkts 0 out DE pkts 0
out bcast pkts 45 out bcast bytes 3030
5 minute input rate 0 bits/sec, 0 packets/sec
5 minute output rate 0 bits/sec, 0 packets/sec
pvc create time 00:39:49, last time pvc status changed 00:27:29

DLCI = 53, DLCI USAGE = LOCAL, PVC STATUS = ACTIVE, INTERFACE = Serial0/1/1

input pkts 64 output pkts 82 in bytes 4206
out bytes 6612 dropped pkts 0 in pkts dropped 0
out pkts dropped 0 out bytes dropped 0
in FECN pkts 0 in BECN pkts 0 out FECN pkts 0
out BECN pkts 0 in DE pkts 0 out DE pkts 0
out bcast pkts 38 out bcast bytes 2532
5 minute input rate 0 bits/sec, 0 packets/sec
5 minute output rate 0 bits/sec, 0 packets/sec
pvc create time 00:33:49, last time pvc status changed 00:27:19

DLCI = 54, DLCI USAGE = UNUSED, PVC STATUS = ACTIVE, INTERFACE = Serial0/1/1

input pkts 0 output pkts 0 in bytes 0
out bytes 0 dropped pkts 0 in pkts dropped 0
out pkts dropped 0 out bytes dropped 0
in FECN pkts 0 in BECN pkts 0 out FECN pkts 0
out BECN pkts 0 in DE pkts 0 out DE pkts 0
out bcast pkts 0 out bcast bytes 0 5 minute input rate 0 bits/sec,
0 packets/sec
5 minute output rate 0 bits/sec, 0 packets/sec
pvc create time 00:00:59, last time pvc status changed 00:00:59

Atlanta# show frame-relay map
Serial0/0/0.3 (up): point-to-point dlci, dlci 54(0x36,0xC60), broadcast
status defined, active
Serial0/0/0.2 (up): point-to-point dlci, dlci 53(0x35,0xC50), broadcast
status defined, active
Serial0/0/0.1 (up): point-to-point dlci, dlci 52(0x34,0xC40), broadcast
status defined, active

Atlanta# debug frame-relay lmi
Frame Relay LMI debugging is on
Displaying all Frame Relay LMI data

Serial0/0/0(out): StEnq, myseq 163, yourseen 161, DTE up
datagramstart = 0x45AED8, datagramsize = 13
FR encap = 0xFCF10309
00 75 01 01 01 03 02 A3 A1

Serial0/0/0(in): Status, myseq 163
RT IE 1, length 1, type 1
KA IE 3, length 2, yourseq 162, myseq 163
```

The **show frame-relay pvc** command lists useful management information. In particular, the output includes a variety of counters and rates for packets going over each permanent virtual circuit (PVC). Also, the PVC status is a great place to start when troubleshooting.

The **show frame-relay map** command lists mapping information. With the earlier example of a fully meshed network, in which the configuration did not use any subinterfaces, a Layer 3 address was listed with each DLCI. In this example, a DLCI is listed in each entry, but no mention of corresponding Layer 3 addresses is made. The whole point of mapping is to correlate a Layer 3 address to a Layer 2 address, but there is no Layer 3 address in the **show frame-relay map** command output! The reason is that with point-to-point subinterfaces routers can find the correct mapping information just from the local configuration, as follows:

- A router matches a route that forwards packet out a point-to-point subinterface.
- The router looks for the one (and only) **frame-relay interface-dlci** configuration command on that subinterface and uses that DLCI when encapsulating the packet.

Finally, the **debug frame-relay lmi** output lists information for the sending and receiving LMI inquiries. The switch sends the status message, and the data terminal equipment (DTE) (router) sends the status inquiry. The default setting with Cisco IOS software is to send, and to expect to receive, these status messages. The Cisco IOS software **no keepalive** command is used to disable the use of LMI status messages. Unlike other interfaces, Cisco keepalive messages do not flow from router to router over Frame Relay. Instead, they are simply used to detect whether the router has connectivity to its local Frame Relay switch.

Configuring with Multipoint Subinterfaces

You can also choose to use multipoint subinterfaces for a Frame Relay configuration. This last sample network, based on the network shown in Figure 14-6, uses both multipoint and point-to-point subinterfaces. Examples 14-13 through 14-17 show the configuration for this network. Table 14-2 summarizes the addresses and subinterfaces used.

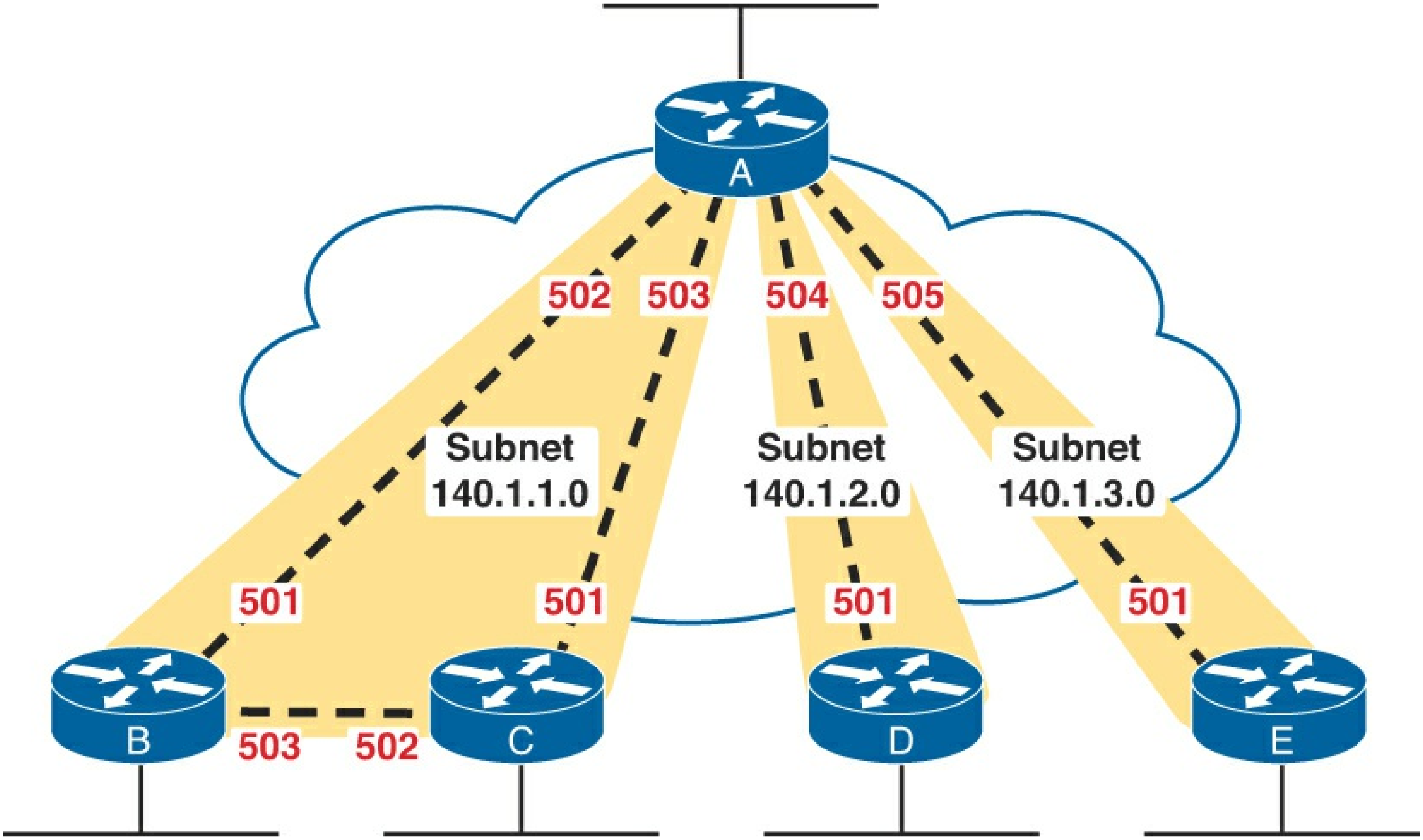


Figure 14-6. Hybrid of Full and Partial Mesh, with Subnets and Local DLCIs

Example 14-13. Router A Configuration

Click here to view code image

```
interface serial0/1/1
encapsulation frame-relay
!
interface serial 0/1/1.1 multipoint
ip address 140.1.1.1 255.255.255.0
frame-relay interface-dlci 502
frame-relay interface-dlci 503
```

```
!
interface serial 0/1/1.2 point-to-point
ip address 140.1.2.1 255.255.255.0
frame-relay interface-dlci 504
!
interface serial 0/1/1.3 point-to-point
ip address 140.1.3.1 255.255.255.0
frame-relay interface-dlci 505
```

Example 14-14. Router B Configuration

Click here to view code image

```
interface serial0/1/1
encapsulation frame-relay
!
interface serial 0/1/1.1 multipoint
ip address 140.1.1.2 255.255.255.0
frame-relay interface-dlci 501
frame-relay interface-dlci 503
```

Example 14-15. Router C Configuration

Click here to view code image

```
interface serial0/1/1
encapsulation frame-relay
!
interface serial 0/1/1.1 multipoint
ip address 140.1.1.3 255.255.255.0
frame-relay interface-dlci 501
frame-relay interface-dlci 502
```

Example 14-16. Router D Configuration

Click here to view code image

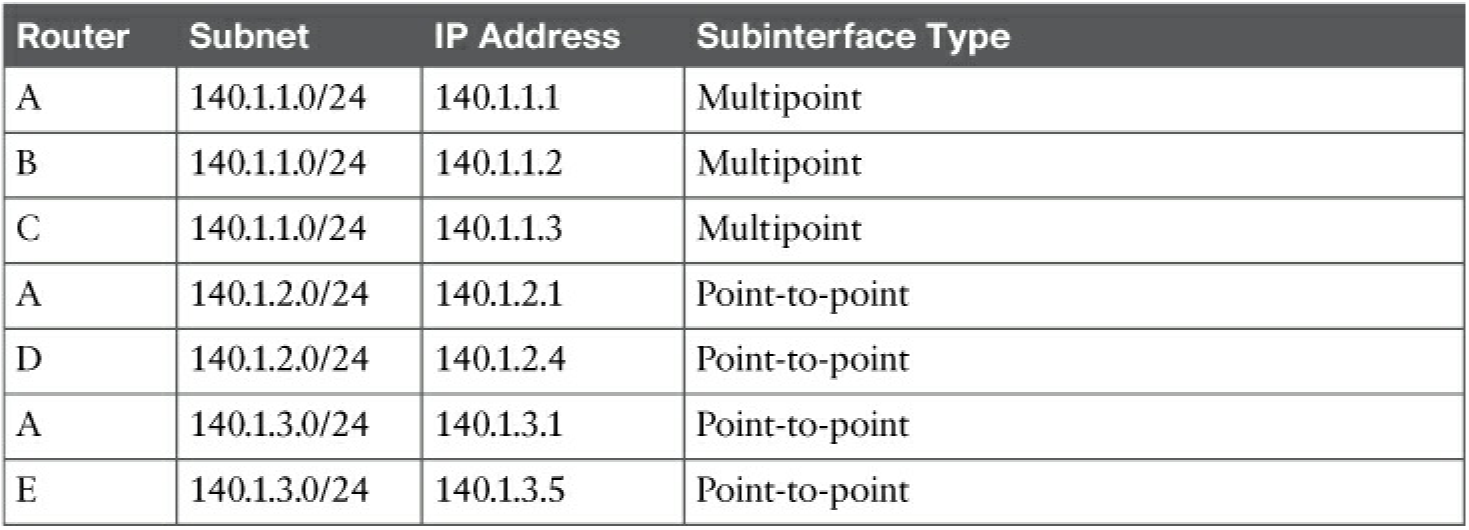
```
interface serial0/0/0
encapsulation frame-relay
!
interface serial 0/1/1.1 point-to-point
ip address 140.1.2.4 255.255.255.0
frame-relay interface-dlci 501
```

Example 14-17. Router E Configuration

Click here to view code image

```
interface serial0/0/0
encapsulation frame-relay
!
interface serial 0/1/1.1 point-to-point
ip address 140.1.3.5 255.255.255.0
frame-relay interface-dlci 501
```

Table 14-2. IP Addresses with Point-to-Point and Multipoint Subinterfaces



Router	Subnet	IP Address	Subinterface Type
A	140.1.1.0/24	140.1.1.1	Multipoint
B	140.1.1.0/24	140.1.1.2	Multipoint
C	140.1.1.0/24	140.1.1.3	Multipoint
A	140.1.2.0/24	140.1.2.1	Point-to-point
D	140.1.2.0/24	140.1.2.4	Point-to-point
A	140.1.3.0/24	140.1.3.1	Point-to-point
E	140.1.3.0/24	140.1.3.5	Point-to-point

Multipoint subinterfaces work best when you have a full mesh between a set of routers. On Routers A, B, and C, a multipoint subinterface is used for the configuration referencing the other two routers, because you can think of these three routers as forming a fully meshed subset of the network.

The term *multipoint* simply means that there is more than one VC, so you can send and receive to and from more than one VC on the subinterface. Like point-to-point subinterfaces, multipoint subinterfaces use the **frame-relay interface-dlci** command. Notice that there are two commands for each multipoint subinterface in this case, because each of the two PVCs associated with this subinterface must be identified as being used with that subinterface.

Router A is the only router using both multipoint and point-to-point subinterfaces. On Router A's multipoint serial 0/1/1.1 interface, DLCIs for Router B and Router C are listed. On Router A's other two subinterfaces, which are point-to-point, only a single DLCI needs to be listed. In fact, only one **frame-relay interface-dlci** command is allowed on a point-to-point subinterface because only one VC is allowed. Otherwise, the configurations between the two types are similar.

No mapping statements are required for the configurations shown in Examples 14-13 through 14-17 because Inverse ARP is enabled on the multipoint subinterfaces by default. No mapping is ever needed for the point-to-point subinterface because the only DLCI associated with the interface is statically configured with the **frame-relay interface-dlci** command.

Example 14-18 lists another **show frame-relay map** command, showing the mapping information learned by Inverse ARP for the multipoint subinterface. Notice that the output now includes the Layer 3 addresses, whereas the same command when using point-to-point subinterfaces (in Example 14-12) did not. The router needs mapping information on multipoint subinterfaces so that when the router routes packets out that subinterface, the router can choose the correct DLCI to use when encapsulating the packet.

Example 14-18. Frame Relay Maps and Inverse ARP on Router C

Click here to view code image

```
RouterC# show frame-relay map
Serial0/1/1.1 (up): ip 140.1.1.1 dlci 501(0x1F5,0x7C50), dynamic,
broadcast,, status defined, active
Serial0/1/1.1 (up): ip 140.1.1.2 dlci 502(0x1F6,0x7C60), dynamic,
broadcast,, status defined, active
```

OSPF Issues on Frame Relay Multipoint and Physical Interfaces

In many enterprise networks that use Frame Relay, the engineers choose to use only point-to-point subinterfaces for Frame Relay. Many Frame Relay WANs connect remote sites to a central site, so the point-to-point model works well. Also, Open Shortest Path First (OSPF) and Enhanced Interior Gateway Routing Protocol (EIGRP) both work well with default settings over point-to-point Frame Relay subinterfaces.

As it turns out, OSPF requires a little more configuration attention when using Frame Relay configurations with multipoint or physical interfaces. This brief section summarizes the issues.

Routers using OSPF do not become neighbors over a Frame Relay physical interface or a multipoint subinterface if using only the OSPF configuration discussed in Chapter 8, "Implementing OSPF for IPv4." The issue? Frame Relay physical and multipoint subinterfaces, by default, use an OSPF network type of nonbroadcast. This OSPF network type means that the router will not attempt to dynamically discover any OSPF neighbors on that interface.

The OSPF problem has multiple solutions, but the simplest is to just change OSPF to use a different OSPF network type on the Frame Relay interfaces. (Chapter 8 introduced the idea of OSPF network types for interfaces, but you needed knowledge about Frame Relay before learning about this one small issue and its solution.) The specific solution: Change the OSPF network type to point-to-multipoint, which lets the routers dynamically discover each other over the physical or multipoint subinterface.

For instance, the previous examples (Examples 14-13, 14-14, and 14-15) showed routers A, B, and C all using a multipoint subinterface and sharing the same subnet. If using OSPF, all three routers should become OSPF neighbors. To make OSPF work between those routers, besides the expected OSPF configuration to enable OSPF on the multipoint subinterface of each route, use the **ip ospf network point-to-multipoint** command on all three router's multipoint subinterface. This command changes the OSPF network type to point-to-multipoint, which tells each router to dynamically discover neighbors (and to not use a designated router/backup designated router [DR/BDR]).

> **Note**
>
> Study tip: When reading this chapter for the first time, take a break before moving into this troubleshooting section. Take some time to practice Frame Relay configuration using whatever lab choice you made (real gear, simulator, and so on).

Frame Relay Troubleshooting

Frame Relay has many features and options that you can configure. For both real life and the exams, troubleshooting Frame Relay problems often means that you need to look at all the routers' configurations and make sure that the configurations meet the requirements. The LMI types must match or be autosensed, the Layer 3 mapping information must be learned or statically mapped, the right DLCI values must be associated with each subinterface, and so on. So, to be well prepared for the CCNA exams, you should review and memorize the many Frame Relay configuration options and what each option means.

However, the exams may have Frame Relay questions that require you to determine a problem without looking at the configuration. This second major section of the chapter examines Frame Relay troubleshooting, with an emphasis on how to use **show** commands, along with the symptoms of a problem to isolate the root cause of the problem.

A Suggested Frame Relay Troubleshooting Process

To isolate a Frame Relay problem, the process should start with some pings. Optimally, pings from an end-user host on a LAN to another host on a remote LAN can quickly determine whether the network currently can meet the true end goal of delivering packets between computers. If that ping fails, a ping from one router to the other router's Frame Relay IP address is the next step. If that ping works, but the end user's ping failed, the problem probably has something to do with Layer 3 issues (troubleshooting those issues was well covered in Chapters 4, "Troubleshooting IPv4 Routing Part I," 5, "Troubleshooting IPv4 Routing Part II," and 11, "Troubleshooting IPv4 Routing Protocols"). However, if a ping from one router to another router's Frame Relay IP address fails, the problem is most likely related to the Frame Relay network.

This section focuses on troubleshooting problems when a Frame Relay router cannot ping another router's Frame Relay IP address. At that point, the engineer should ping the Frame Relay IP addresses of all the other routers on the other end of each VC to determine the following:

> Do the pings fail for all remote routers' Frame Relay IP addresses or do some pings fail and some pings work?

For example, Figure 14-7 shows a sample Frame Relay network that will be used with the remaining examples in this chapter. If R1 tried to ping R2's Frame Relay IP address (10.1.2.2 in this case) and failed, the next question is whether R1's pings to R3 (10.1.34.3) and R4 (10.1.34.4) work.

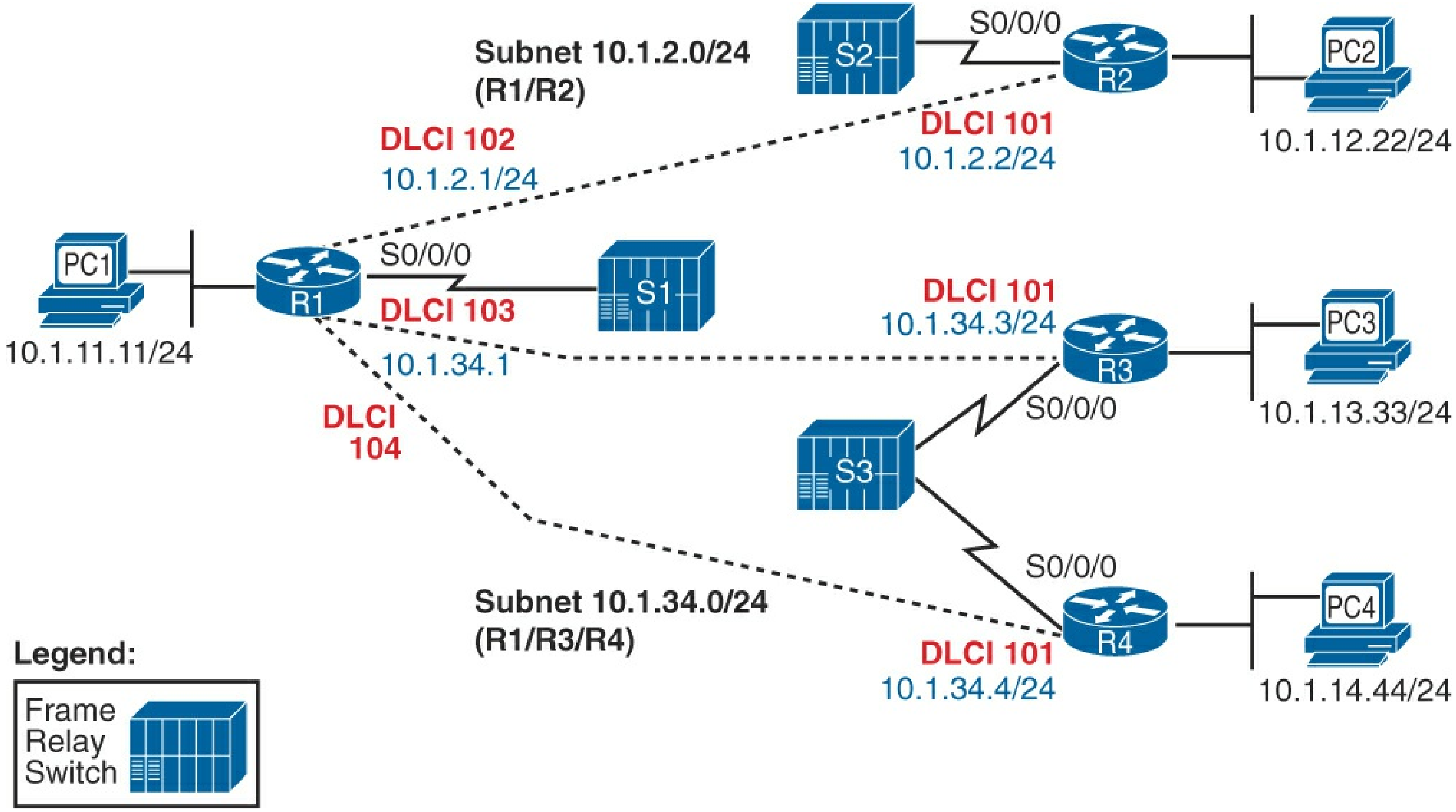


Figure 14-7. Sample Frame Relay Network for the Troubleshooting Examples

This chapter organizes its explanations of how to troubleshoot Frame Relay based on this first problem isolation step. The following list summarizes the major actions, with each step in the following list being examined in order following the list.

If a Frame Relay router's pings fail for all remote routers whose VCs share a single access link, do the following:

Key Topic

Step 1. Check for Layer 1 problems on the access link between the router and the local Frame Relay switch (all routers).

Step 2. Check for Layer 2 problems on the access link, particularly encapsulation and LMI.

After resolving any problems in the first two steps, or if the original ping tests showed that the Frame Relay router can ping some, but not all, of the other Frame Relay routers whose VCs share a single access link, follow these steps:

Step 3. Check for PVC problems based on the PVC status and subinterface status.

Step 4. Check for Layer 2 or 3 problems with both static and dynamic (Inverse ARP) mapping.

Step 5. Check for Layer 2 or 3 problems related to a mismatch of end-to-end encapsulation (cisco or ietf).

Step 6. Check for other Layer 3 issues, including mismatched subnets.

The rest of this chapter explains some of the details of each step of this suggested troubleshooting process.

Layer 1 Issues on the Access Link (Step 1)

If a router's physical interface used for the Frame Relay access link is not in an "up and up" state, the router cannot send any frames over the link. If the interface has a line status (the first interface status code) of down, the interface most likely has a Layer 1 issue.

From a Layer 1 perspective, a Frame Relay access link is merely a leased line between a router and a Frame Relay switch. As such, the exact same Layer 1 issues exist for this link as for a point-to-point leased line. Because the possible root causes and suggested troubleshooting steps mirror what should be done on a leased line, refer to the section "Troubleshooting Layer 1 Problems" in Chapter 12, "Implementing Point-to-Point WANs," for more information about this step.

Layer 2 Issues on the Access Link (Step 2)

If a router's physical interface line status is up, but the line protocol status (second status code) is down, the link usually has a Layer 2 problem between the router and the local Frame Relay switch. With Frame Relay interfaces, the problem is often related to either the **encapsulation** command or the Frame Relay LMI.

The potential problem related to the **encapsulation** command is simple to check. If a router's serial interface configuration omits the **encapsulation frame-relay** interface subcommand but the physical access link is working, the physical interface settles into an up/down state. If the configuration is unavailable, the **show interfaces** command can be used to see the configured encapsulation type, which is listed in the first few lines of command output.

The other potential problem relates to the LMI. LMI status messages flow in both directions between a router (data terminating equipment [DTE]) and Frame Relay switch (data circuit-terminating equipment [DCE]) for two main purposes:

Key Topic

- For the DCE to inform the DTE about each VC's DLCI and its status
- To provide a keepalive function so that the DTE and DCE can easily tell when the access link can no longer pass traffic

A router places the physical link in an up/down state when the link physically works, but the router ceases to hear LMI messages from the switch. With the interface not in an up/up state, the router does not attempt to send any IP packets out the interface, so all pings should fail at this point.

A router might cease to receive LMI messages from the switch because of both legitimate reasons and mistakes. The normal legitimate purpose for the LMI keepalive function is that if the link really is having problems, and cannot pass any data, the router can notice the loss of keepalive messages and bring the link down. This allows the router to use an alternative route, assuming that an alternative route exists. However, a router might cease to receive LMI messages and bring down the interface because of the following mistakes:

- Disabling LMI on the switch, but leaving it enabled on the router
- Configuring different LMI types on the router (with the **frame-relay lmi-type** *type* physical interface subcommand) and the switch, so that the router and Frame Relay switch do not understand each other's LMI messages

You can easily check for both encapsulation and LMI using the **show frame-relay lmi** command. This command lists output for interfaces only if the interface has the **encapsulation frame-relay** command configured, so you can quickly confirm whether the **encapsulation frame-relay** command is configured on the correct serial interfaces. This command also lists the LMI type used by the router, and it shows counters for the number of LMI messages sent and received. Example 14-19 shows an example from router R1 in Figure 14-6.

Example 14-19. show frame-relay lmi **Command on R1**

Click here to view code image

```
R1# show frame-relay lmi
```

```
LMI Statistics for interface Serial0/0/0 (Frame Relay DTE) LMI TYPE = ANSI
Invalid Unnumbered info 0 Invalid Prot Disc 0
Invalid dummy Call Ref 0 Invalid Msg Type 0
Invalid Status Message 0 Invalid Lock Shift 0
Invalid Information ID 0 Invalid Report IE Len 0
Invalid Report Request 0 Invalid Keep IE Len 0
Num Status Enq. Sent 122 Num Status msgs Rcvd 34
Num Update Status Rcvd 0 Num Status Timeouts 88
Last Full Status Req 00:00:04 Last Full Status Rcvd 00:13:24
```

For this example, router R1 was statically configured with the **frame-relay lmi-type ansi** interface subcommand, with switch S1 still using LMI type cisco. At the point in time that the configuration was changed, the statistics for the number of sent and received status messages were both at 34. (When working, these numbers will grow at the same rate.) From that point forward, R1 has now sent 88 ANSI status messages, for a total of 122 status messages sent. The number of status messages received still sits at 34, because R1 no longer understands the Cisco LMI messages sent by the switch. Also, R1 has been expecting an ANSI status message for the last 88 LMI status time intervals, as noted in the status timeouts counter.

If repeated use of the **show frame-relay lmi** command shows that the number of status messages received remains the same, the likely cause, other than a truly nonworking link, is that the LMI types do not match. The best solution is to allow for LMI autosense by configuring the **no frame-relay lmi-type** physical interface subcommand. Alternatively, configure the same LMI type that is used by the switch.

If you troubleshoot and fix any problems found in Steps 1 and 2 on all Frame Relay connected routers, all the routers' access link physical interfaces should be in an up/up state. The last four steps examine issues that apply to individual PVCs and neighbors.

PVC Problems and Status (Step 3)

The goal at this step in the troubleshooting process is to discover the DLCI of the PVC used to reach a particular neighbor, and then find out if the PVC is working.

To determine the correct PVC, particularly if little or no configuration or documentation is available, you have to start with the failed **ping** command for the neighboring router's IP address on the Frame Relay network. From there, you can follow this chain of logic:

Step 3a. Discover the IP address and mask of each Frame Relay interface/subinterface (**show interfaces**, **show ip interface brief**) and calculate the connected subnets.

Step 3b. Compare the IP address of the neighbor (from the failed **ping** command) and pick the local interface/subinterface whose connected subnet is the same subnet.

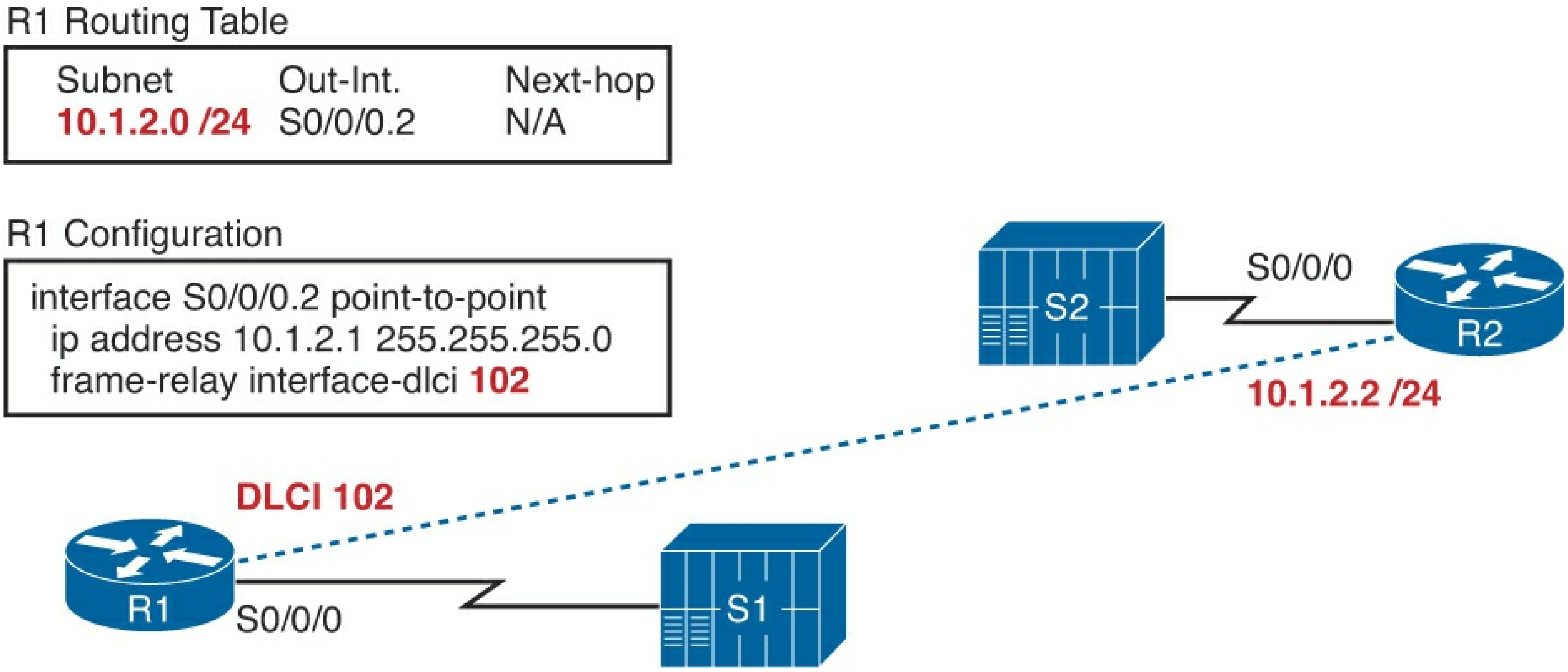
Step 3c. Discover the PVCs assigned to that interface or subinterface (**show frame-relay pvc**).

Step 3d. If more than one PVC is assigned to the interface or subinterface, determine which PVC is used to reach a particular neighbor (**show frame-relay map**).

> **Note**
>
> As a reminder, lists like this one are meant for convenient reference when you read the chapter. It is easy to find the list when you study and want to remember a particular part of how to attack a given problem. You do not need to memorize the list or practice it until you internalize the information.

Steps 3a, 3b, 3c, and 3d discover the correct PVC to examine. After it is discovered, Step 3 in the suggested troubleshooting process interprets the status of that PVC, and the associated interface or subinterface, to determine the cause of any problems.

This section takes a closer look at an example in which R1 cannot ping R2's 10.1.2.2 Frame Relay IP address from Figure 14-7. Before focusing on the process to determine which VC is used, it is helpful to see the final answer, so Figure 14-8 lists some of the details. For this example, R1's **ping 10.1.2.2** command fails in this case.



Subnet	Out-Int.	Next-hop
10.1.2.0 /24	S0/0/0.2	N/A

```
interface S0/0/0.2 point-to-point
 ip address 10.1.2.1 255.255.255.0
 frame-relay interface-dlci 102
```

Figure 14-8. Configuration Facts Related to R1's Failed ping 10.1.2.2 **Command**

Find the Connected Subnet and Outgoing Interface (Steps 3a and 3b)

The first two substeps to find R1's PVC (DLCI) connecting to R2 (Substeps 3a and 3b) should be relatively easy assuming that you have already finished Parts II and III of this book. Any time you ping the Frame Relay IP address of a neighboring router, that IP address should be in one of the subnets also connected to the local router. To find the interface used on a local router when forwarding packets to the remote router, you just have to find that common connected subnet.

In this example, with R1 pinging 10.1.2.2, Example 14-20 shows a few commands that confirm that R1's S0/0/0.2 subinterface is connected to subnet 10.1.2.0/24, which includes R2's 10.1.2.2 IP address.

Example 14-20. Finding Subnet 10.1.2.0/24 and Subinterface S0/0/0.2

Click here to view code image

```
R1> show ip interface brief
Interface IP-Address OK? Method Status Protocol
FastEthernet0/0 10.1.11.1 YES NVRAM up up
FastEthernet0/1 unassigned YES NVRAM administratively down down
Serial0/0/0 unassigned YES NVRAM up up
Serial0/0/0.2 10.1.2.1 YES NVRAM down down
Serial0/0/0.5 10.1.5.1 YES manual down down
Serial0/0/0.34 10.1.34.1 YES NVRAM up up

R1# show interfaces s 0/0/0.2
Serial0/0/0.2 is down, line protocol is down
Hardware is GT96K Serial
Internet address is 10.1.2.1/24
MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,
reliability 255/255, txload 1/255, rxload 1/255
Encapsulation FRAME-RELAY
Last clearing of "show interface" counters never
! Lines omitted for brevity
```

Find the PVCs Assigned to That Interface (Step 3c)

The **show frame-relay pvc** command directly answers the question of which PVCs have been assigned to which interfaces and subinterfaces. If the command is issued with no parameters, the command lists about ten lines of output for each VC, with the end of the first line listing the associated interface or subinterface. Example 14-21 lists the beginning of the command output.

Example 14-21. Correlating Subinterface S0/0/0.2 to the PVC with DLCI 102

Click here to view code image

```
R1> show frame-relay pvc

PVC Statistics for interface Serial0/0/0 (Frame Relay DTE)

Active Inactive Deleted Static
Local 1 2 0 0
Switched 0 0 0 0
Unused 0 0 0 0

DLCI = 102, DLCI USAGE = LOCAL, PVC STATUS = INACTIVE, INTERFACE = Serial0/0/0.2

input pkts 33 output pkts 338 in bytes 1952
out bytes 29018 dropped pkts 0 in pkts dropped 0
out pkts dropped 0 out bytes dropped 0
in FECN pkts 0 in BECN pkts 0 out FECN pkts 0
out BECN pkts 0 in DE pkts 0 out DE pkts 0
out bcast pkts 332 out bcast bytes 28614
5 minute input rate 0 bits/sec, 0 packets/sec
5 minute output rate 0 bits/sec, 0 packets/sec
pvc create time 00:30:05, last time pvc status changed 00:04:14

DLCI = 103, DLCI USAGE = LOCAL, PVC STATUS = INACTIVE, INTERFACE = Serial0/0/0.34

input pkts 17 output pkts 24 in bytes 1106
out bytes 2086 dropped pkts 0 in pkts dropped 0
out pkts dropped 0 out bytes dropped 0
in FECN pkts 0 in BECN pkts 0 out FECN pkts 0
out BECN pkts 0 in DE pkts 0 out DE pkts 0
out bcast pkts 11 out bcast bytes 674
5 minute input rate 0 bits/sec, 0 packets/sec
5 minute output rate 0 bits/sec, 0 packets/sec
pvc create time 00:30:07, last time pvc status changed 00:02:57

DLCI = 104, DLCI USAGE = LOCAL, PVC STATUS = ACTIVE, INTERFACE = Serial0/0/0.34

input pkts 41 output pkts 42 in bytes 2466
out bytes 3017 dropped pkts 0 in pkts dropped 0
out pkts dropped 0 out bytes dropped 0
in FECN pkts 0 in BECN pkts 0 out FECN pkts 0
out BECN pkts 0 in DE pkts 0 out DE pkts 0
out bcast pkts 30 out bcast bytes 1929
5 minute input rate 0 bits/sec, 0 packets/sec
5 minute output rate 0 bits/sec, 0 packets/sec
pvc create time 00:30:07, last time pvc status changed 00:26:17
```

To find all the PVCs associated with an interface or subinterface, just scan the highlighted parts of the output in Example 14-21. In this case, S0/0/0.2 is listed with only one PVC, the one with DLCI 102, so only one PVC is associated with S0/0/0.2 in this case.

Determine Which PVC Is Used to Reach a Particular Neighbor (Step 3d)

If the router's configuration associates more than one PVC with one interface or subinterface, the next step is to figure out which of the PVCs is used to send traffic to a particular neighbor. For instance, Example 14-21 shows R1 uses a multipoint subinterface S0/0/0.34 with DLCIs 103 and 104. So, if you were troubleshooting a problem in which the **ping 10.1.34.3** command failed on R1, the next step would be to determine which of the two DLCIs (103 or 104) identifies the VC connecting R1 to R3.

Unfortunately, you cannot always find the answer without looking at other documentation. The only **show** command that can help is **show frame-relay map**, which can correlate the next-hop IP address and DLCI. Unfortunately, if the local router relies on Inverse ARP, the local router cannot learn the mapping information right now either, so the mapping table might not have any useful information in it. However, if static mapping is used, the correct PVC/DLCI can be identified.

In the example of R1 failing when pinging 10.1.2.2 (R2), only one PVC is associated with the correct interface (S0/0/0.2). As a result, this example ignores this step and moves on to look at PVC status.

PVC Status

At this point in major troubleshooting Step 3, the correct outgoing interface/subinterface and correct PVC/DLCI have been identified. Finally, the PVC status can be examined to see if it means that the PVC has a problem.

Routers use four different PVC status codes. A router learns about two of the possible status values, *active* and *inactive*, via

LMI messages from the Frame Relay switch. The switch's LMI message lists all DLCIs for all configured PVCs on the access link and whether the PVC is currently usable (active) or not (inactive). An LMI message that lists these states means:

Active: The Frame Relay network knows about the PVC with the listed DLCI, and the PVC is working right now.

Inactive: The Frame Relay network knows about the PVC with the listed DLCI, and the PVC is not working right now.

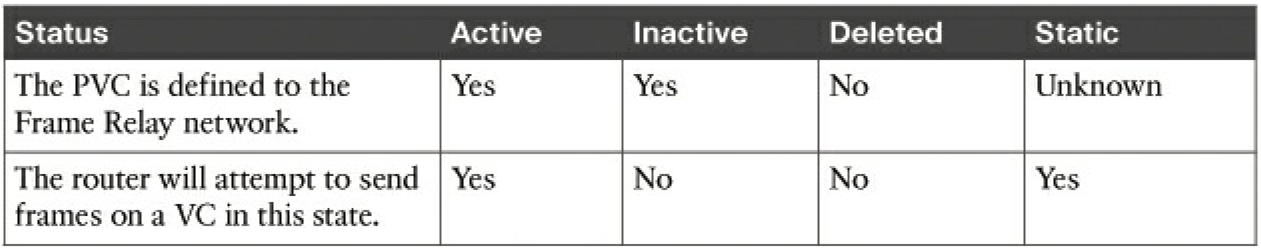
Routers have two other PVC states that require a little more thought to understand. First, the static state means that the router has configured a DLCI for some PVC but the LMI is down. Because the LMI is down, the router does not know whether the PVC will work, because the router receives no LMI status messages. However, the router can at least send frames using those DLCIs and hope that the Frame Relay network can deliver them.

The other PVC state, *deleted*, means that the router configuration refers to the DLCI, but the LMI is working and lists no information about that DLCI value. The LMI status messages list status for all the PVCs defined over the access link, so this state means that the Frame Relay network does not have a definition for the PVC. Basically, this state means that the router has configured the DLCI but the switch has not.

Table 14-3 summarizes the four Frame Relay PVC status codes.

Key Topic

Table 14-3. PVC Status Values



Status	Active	Inactive	Deleted	Static
The PVC is defined to the Frame Relay network.	Yes	Yes	No	Unknown
The router will attempt to send frames on a VC in this state.	Yes	No	No	Yes

As noted in the last row of the table, routers only send data over PVCs in an active or static state. Also even if the PVC is in a static state, there is no guarantee that the Frame Relay network can actually send frames over that PVC, because the static state implies that LMI is turned off and that the router has not learned any status information.

The next step in the troubleshooting process is to find the status of the PVC used to reach a particular neighbor. Continuing with the problem of R1 failing when pinging R2 (10.1.2.2), Example 14-22 shows the status of the PVC with DLCI 102, as identified earlier.

Example 14-22. show frame-relay pvc **Command on R1**

Click here to view code image

```
R1> show frame-relay pvc 102

PVC Statistics for interface Serial0/0/0 (Frame Relay DTE)

DLCI = 102, DLCI USAGE = LOCAL, PVC STATUS = INACTIVE, INTERFACE = Serial0/0/0.2

input pkts 22 output pkts 193 in bytes 1256
out bytes 16436 dropped pkts 0 in pkts dropped 0
out pkts dropped 0 out bytes dropped 0
in FECN pkts 0 in BECN pkts 0 out FECN pkts 0
out BECN pkts 0 in DE pkts 0 out DE pkts 0
out bcast pkts 187 out bcast bytes 16032
5 minute input rate 0 bits/sec, 0 packets/sec
5 minute output rate 0 bits/sec, 0 packets/sec
pvc create time 01:12:56, last time pvc status changed 00:22:45
```

In this case, R1 cannot ping R2 because the PVC with DLCI 102 is in an inactive state.

To further isolate the problem and find the root cause, you need to look deeper into the reasons why a PVC can be in an inactive state. First, as always, repeat the same troubleshooting steps on the other router (in this case, R2). If no problems are found on R2, other than an inactive PVC, the problem may be a genuine problem in the Frame Relay provider's network, so a call to the provider may be the next step. However, you may find some other problem on the remote router. For example, to create the failure and **show** commands in this section, R2's access link was shut down, so a quick examination of troubleshooting Step 1 on router R2 would have identified the problem. However, if further troubleshooting shows that both routers list their ends of the PVC in an inactive state, the root cause (in this case) lies within the Frame Relay provider's network.

Finding the root cause of a problem related to a PVC in a deleted state is relatively easy. The deleted status means that the Frame Relay switch's configuration and the router's configuration do not match, with the router configuring a DLCI that is not also configured on the switch. Either the provider said it would configure a PVC with a particular DLCI and did not, or the router engineer configured the wrong DLCI value.

Subinterface Status

Subinterfaces have a line status and protocol status code, just like physical interfaces. However, because subinterfaces are virtual, the status codes and their meanings differ a bit from physical interfaces. This section briefly examines how Frame Relay subinterfaces work and how IOS decides whether a Frame Relay subinterface should be in an up/up state or a down/down state.

Frame Relay configuration associates one or more DLCIs with a subinterface using two commands: **frame-relay interface-dlci** and **frame-relay map**. Of all the DLCIs associated with a subinterface, IOS uses the following rules to determine the status of a subinterface:

Key Topic

- **Down/down:** All the DLCIs associated with the subinterface are inactive or deleted, or the underlying physical interface is not in an up/up state.
- **Up/up:** At least one of the DLCIs associated with the subinterface is active or static.

For example, to cause the problems shown in Example 14-22, R2 and R3 simply shut down their Frame Relay access links. Figure 14-9 shows the next LMI status message that switch S1 sends to R1.

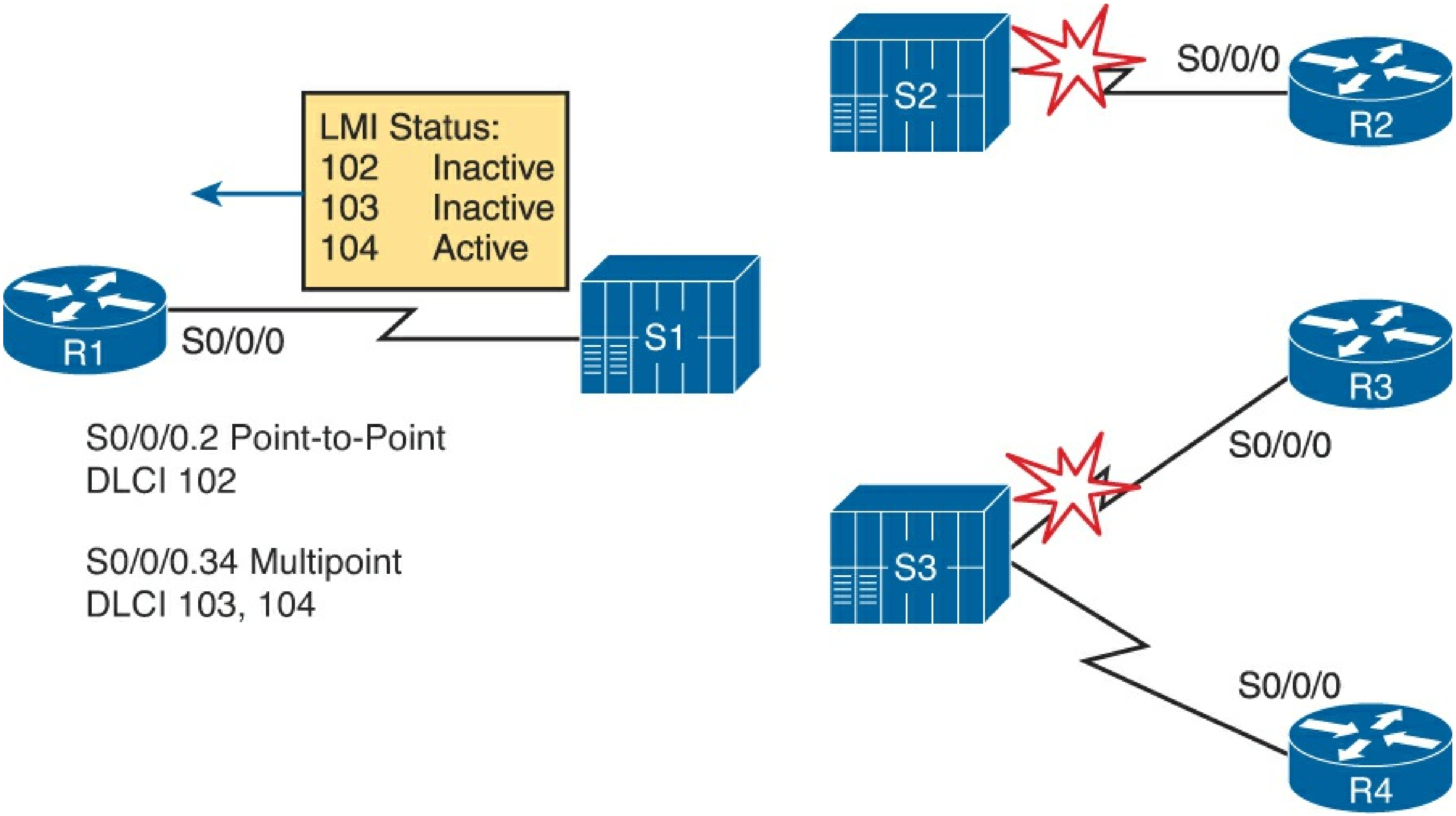


Figure 14-9. Results of Shutting Down R2 and R3 Access Links

As shown in the figure, R1 uses a point-to-point subinterface (S0/0/0.2) for the VC connecting to R2 and a multipoint subinterface (S0/0/0.34) associated with the VCs to R3 and R4 (103 and 104, respectively). Earlier, the beginning of Example 14-20 shows that S0/0/0.2 is in a down/down state; the reason is that the only DLCI associated with the subinterface (102) is inactive. However, S0/0/0.34 has two DLCIs, one of which is active, so IOS leaves S0/0/0.34 in an up/up state.

It is useful to look at subinterface status when troubleshooting, but keep in mind that just because a subinterface is up, if it is a multipoint subinterface the up/up state does not necessarily mean that all DLCIs associated with the subinterface are working.

Frame Relay Mapping Issues (Step 4)

If you follow the first three steps of the troubleshooting process suggested in this chapter and resolve the problems at each step, at this point each router's access link interfaces should be in an up/up state, and the PVC between the two routers should be in an active (or static) state. If the routers still cannot ping each other's Frame Relay IP addresses, the next thing to check is the Frame Relay address mapping information, which maps DLCIs to next-hop IP addresses.

This section does not repeat the detailed coverage of address mapping that appears in this chapter. However, for perspective, the following list points out some tips and hints as reminders when you perform this troubleshooting step:

On point-to-point subinterfaces:

- These subinterfaces do not need Inverse ARP or static mapping.
- IOS automatically maps any other IP addresses in the same subnet as a point-to-point subinterface as being reachable via the only DLCI on the subinterface.
- The **show frame-relay map** command output does list point-to-point subinterfaces, but with no next-hop IP address and no "dynamic" notation (which would imply InARP learned the mapping).

On physical interfaces and multipoint subinterfaces

- They need to use either Inverse ARP or static mapping.
- The **show frame-relay map** command should list the remote router's Frame Relay IP address and the local router's local DLCI for each PVC associated with the interface or subinterface. The "dynamic" notation means the mapping was learned with InARP.
- If you're using static mapping, the **broadcast** keyword is needed to support a routing protocol.

For completeness, Example 14-23 shows the output of the **show frame-relay map** command on router R1 from Figure 14-7 with no problems with the mapping. (The earlier problems that were introduced have been fixed.) In this case, interface S0/0/0.2 is a point-to-point subinterface, and S0/0/0.34 is a multipoint with one Inverse ARP-learned mapping and one statically configured mapping.

Example 14-23. show frame-relay map **Command on R1**

Click here to view code image

```
R1# show frame-relay map
Serial0/0/0.34 (up): ip 10.1.34.4 dlci 104(0x68,0x1880), static,
broadcast,
CISCO, status defined, active
Serial0/0/0.34 (up): ip 10.1.34.3 dlci 103(0x67,0x1870), dynamic,
broadcast,, status defined, active
Serial0/0/0.2 (up): point-to-point dlci, dlci 102(0x66,0x1860), broadcast
status defined, active
```

End-to-End Encapsulation (Step 5)

The end-to-end encapsulation on a PVC refers to the headers that follow the Frame Relay header, with two options: the Cisco-proprietary header and an IETF standard header. The configuration details were covered earlier in this chapter, in the section "Configuring the Encapsulation and LMI."

As it turns out, a mismatched encapsulation setting on the routers on opposite ends of the link might cause a problem in one particular case. If one router is a Cisco router using Cisco encapsulation and the other router is a non-Cisco router using IETF encapsulation, pings might fail because of the encapsulation mismatch. However, two Cisco routers can understand both types of encapsulation, so it should not be an issue in networks with only Cisco routers.

Mismatched Subnet Numbers (Step 6)

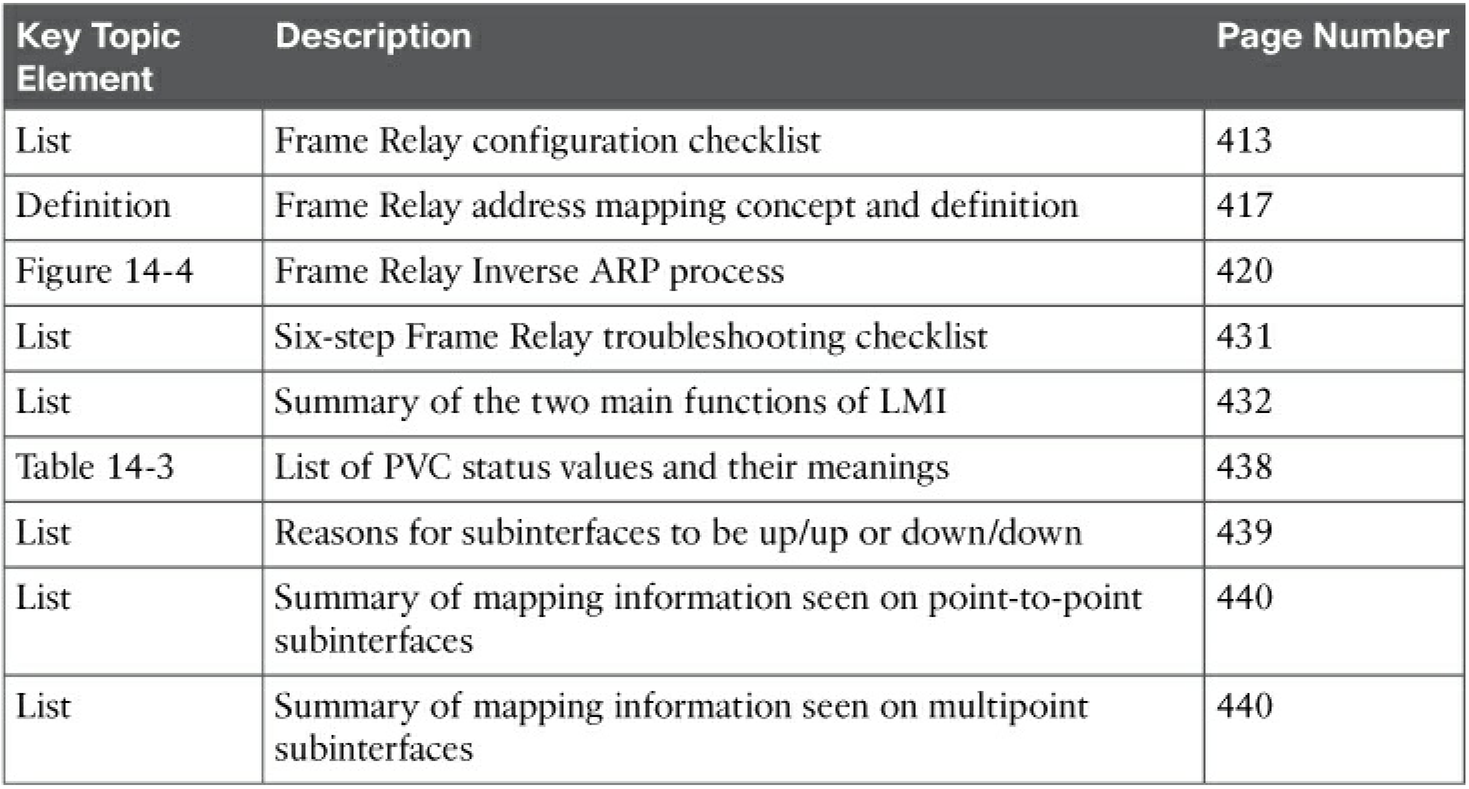
At this point, if the problems found in the first five of the six troubleshooting steps have been resolved, all the Frame Relay problems should be resolved. However, if the two routers on either end of the PVC have mistakenly configured IP addresses in different subnets, the routers will not be able to ping one another, and the routing protocols will not become adjacent. So, as a last step, you should confirm the IP addresses on each router and the masks and ensure that they connect to the same subnet. To do so, just use the **show ip interface brief** and **show interfaces** commands on the two routers.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 14-4 lists these key topics and where each is discussed.

Table 14-4. Key Topics for Chapter 14



Key Topic Element	Description	Page Number
List	Frame Relay configuration checklist	413
Definition	Frame Relay address mapping concept and definition	417
Figure 14-4	Frame Relay Inverse ARP process	420
List	Six-step Frame Relay troubleshooting checklist	431
List	Summary of the two main functions of LMI	432
Table 14-3	List of PVC status values and their meanings	438
List	Reasons for subinterfaces to be up/up or down/down	439
List	Summary of mapping information seen on point-to-point subinterfaces	440
List	Summary of mapping information seen on multipoint subinterfaces	440

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix D, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix E, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Command Reference to Check Your Memory

Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table, read the descriptions on the right side, and see if you remember the command.

Table 14-5. Chapter 14 Configuration Command Reference

Command	Description
encapsulation frame-relay [**ietf**]	Interface configuration mode command that defines the Frame Relay encapsulation that is used rather than HDLC, PPP, and so on
frame-relay lmi-type {**ansi** | **q933a** | **cisco**}	Interface configuration mode command that defines the type of LMI messages sent to the switch
no frame-relay lmi-type	Interface configuration mode command that reverts back to the default LMI setting of autosensing the LMI type
bandwidth *num*	Interface subcommand that sets the router's perceived interface speed
frame-relay map {*protocol protocol-address dlci*} [**broadcast**] [**ietf** | **cisco**]	Interface configuration mode command that statically defines a mapping between a network layer address and a DLCI
frame-relay interface-dlci *dlci* [**ietf** | **cisco**]	Subinterface configuration mode command that links or correlates a DLCI to the subinterface
keepalive *sec*	Interface configuration mode command that defines whether and how often LMI status inquiry messages are sent and expected
interface serial *number.sub* [**point-to-point** | **point-to-multipoint**]	Global configuration mode command that creates a subinterface or references a previously created subinterface
[**no**] **frame-relay inverse-arp**	Physical and multipoint subcommand to disable Frame Relay Inverse ARP (**no inverse-arp**) or enable it

Table 14-6. Chapter 14 EXEC Command Reference

Command	Description
show interfaces [*type number*]	Shows the physical interface status
show frame-relay pvc [**interface** *interface*][*dlci*]	Lists information about the PVC status
show frame-relay lmi [*type number*]	Lists LMI status information
show frame-relay map [*type number*]	Lists Frame Relay mapping information matching next-hop IP addresses to local DLCIs
show interfaces [*type number*]	Lists statistics and details of interface configuration, including the encapsulation type
show ip interface brief	Lists one line of output per interface with IP address and interface status
debug frame-relay lmi	Displays the contents of LMI messages

Chapter 15. Identifying Other Types of WANs

This chapter covers the following exam topics:

WAN Technologies

- Identify Different WAN Technologies
  - Metro Ethernet
  - VSAT
  - Cellular 3G / 4G
  - MPLS
  - T1 / E1
  - ISDN
  - DSL
  - Cable
- Implement and troubleshoot PPPoE

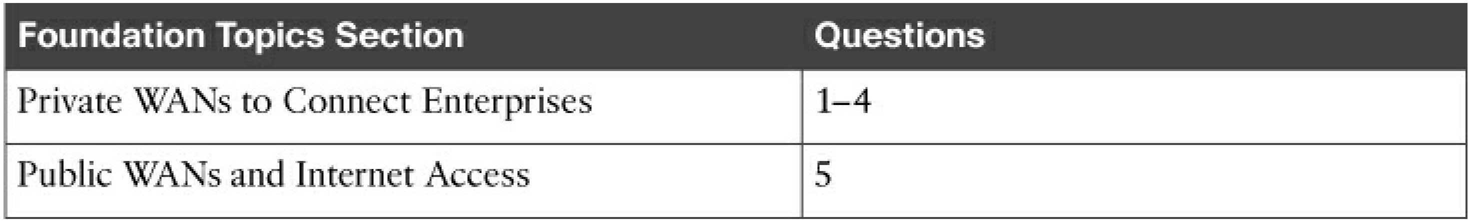
Many of the chapters in this book introduce a topic, and then go deeper, because the related exam requires that deeper knowledge. Unlike most other chapters in this book, this chapter introduces each topic briefly, and then moves on to the next topic. The point of this chapter is to introduce you to the general ideas behind a handful of other WAN protocols.

Just to give the technologies some context, this chapter breaks down the technologies into two major sections. The first looks at WAN technologies used to create private WAN services, usually for businesses. The second section looks at WAN technologies used to access the Internet, whether for businesses or consumers.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the Exam Preparation Tasks section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 15-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Private WANs to Connect Enterprises	1–4
Public WANs and Internet Access	5

1. Which of the following private WAN services operates primarily as a Layer 3 service, delivering IP packets between two customer sites?
   a. Leased line
   b. MPLS
   c. Ethernet WAN
   d. Frame Relay
2. Which of the following private WAN services supports 100-Mbps Ethernet as an access link? (Choose two answers.)
   a. Leased line
   b. MPLS
   c. Ethernet WAN
   d. Frame Relay
3. Which of the following private WAN services would use a serial interface on the customer router? (Choose two answers.)
   a. Leased line
   b. VSAT
   c. Ethernet WAN
   d. Frame Relay
4. Which of the following Internet access technology is considered to be an "always on" service, not requiring the user to do something before sending packets into the Internet? (Choose two answers.)
   a. DSL
   b. Analog dial-up
   c. Cable Internet
   d. ISDN

5. Which of the following Internet access technologies is considered to use symmetric speeds, with the same speed downstream, toward the customer, as upstream, toward the ISP?

a. DSL

b. ISDN

c. Cable Internet

d. None of the above

6. The sample PPPoE configuration for a customer router shows four commands with a parameter of 2. Which two commands must have the same value for the configuration to work correctly? (Choose two answers.)

```
interface dialer 2
dialer pool 2
encapsulation ppp
ppp chap hostname Fred
ppp chap password 2
ip address negotiated
mtu 1492

interface gigabitethernet 0/1
pppoe-client dial-pool-number 2
```

a. interface dialer 2

b. dialer pool 2

c. ppp chap password 2

d. pppoe-client dial-pool-number 2

Answers to the “Do I Know This Already?” quiz:

1 B **2** B and C **3** A and D **4** A and C **5** B **6** B and D

Foundation Topics

Private WANs to Connect Enterprises

WAN services usually create either a private WAN service or a public WAN service. With a private service, one customer connects to the WAN service provider with connections from many sites. The provider promises to forward data between those sites. Later, when a second customer connects to that same WAN service, the WAN service keeps the two customer’s data traffic private. While the data may flow through the same devices inside the provider’s network, the provider never forwards data sent by customer 1 to customer 2, and vice versa, making the network private from the customer perspective.

In contrast, a connection to the Internet relies on the fact that each Internet service provider’s (ISP) customer can and will allow packets from other customers. Adding a connection to the Internet through an ISP announces a willingness to send and receive packets over that connection. To protect that connection, people then must pay attention to security, allowing only the right kinds of traffic over their Internet access links.

You can use most of the WAN technology mentioned in this chapter to build both private WANs and the public Internet. However, some technologies make a better fit in one or the other, so this chapter discusses each WAN technology in a likely place where the technology would be used.

This first section of the chapter looks at WAN technologies in private WAN services, with these WAN technologies:

- Leased lines
- Frame Relay
- Ethernet WANs
- MPLS
- VSAT

Leased Lines

Of all the WAN topics mentioned in this book, leased lines and Frame Relay obviously get the most attention. Chapter 12, "Implementing Point-to-Point WANs," already discussed leased lines, and the data link protocols most often used with them, in some depth. Why mention more about them here in this chapter? To set the stage to make comparisons to the other WAN technologies introduced in this chapter.

One of the ICND2 (and CCNA) exam topics states that you need to be ready to identify various WAN technologies. So, in what ways can you identify leased lines when you see them on the exam? To review a few items, consider this list:

- First, leased lines go by many names, so review the names in Table 12-2, back in Chapter 12, at some point.

Table 15-2. Key Identifiers for Leased Lines

	Leased Line
Typical physical access links	TDM (T1, E1, and so on)
Router interface	Serial
Protocols	HDLC, PPP[1]
WAN service promise	Deliver bits to other end of line

[1] The leased line service does not require or use a data link protocol. However, routers usually use High-Level Data-Link Control (HDLC) or Point-to-Point Protocol (PPP).

- In figures, the generic version shows the generic crooked line that looks like a lightning bolt. Other figures look more like Figure 15-1, which shows the channel service unit/data service unit (CSU/DSU) that is needed for each router; note that the figure shows an external CSU/DSU.

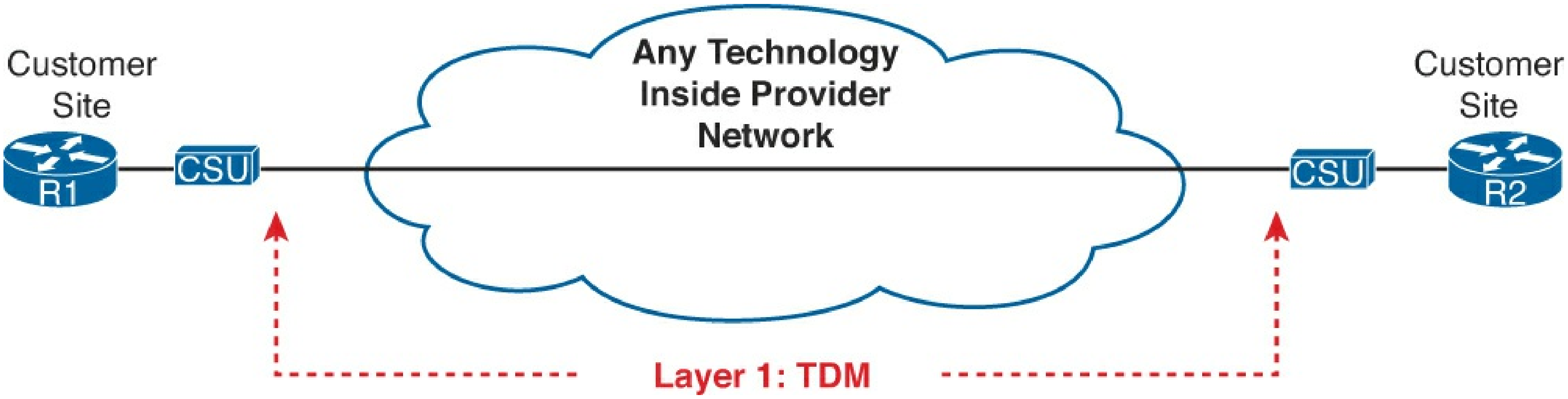


Figure 15-1. Point-to-Point Leased Line

- As for other words, the technology used to create the line includes terms like T-carrier and time-division multiplexing (TDM), as well as the names for the common line speeds: DS1, T1, E1, T3, and E3.
- As for protocols, leased lines provide a Layer 1 service, in that the provider promises to deliver bits to the other end of the line. The service provider lets the customer use any data link and higher-layer protocols that the customer wants to use.

Figure 15-1 shows a sample figure of a leased line, when the figure focuses on the cabling to an external CSU/DSU.

Finally, one goal for this chapter is to help you identify WAN technologies by noticing their differences. To that end, Table 15-2 notes a few key facts about leased lines, with other upcoming tables adding new technologies to similar tables to make some comparisons.

Frame Relay

Frame Relay concepts and terminology should be pretty fresh in your mind after just finishing Chapters 13, "Understanding Frame Relay Concepts," and 14, "Implementing Frame Relay." What items should you watch for to notice Frame Relay WANs in the exam as opposed to other WAN technology? This list gives a few items:

- The access links—the link from the customer router to the Frame Relay network—typically use a leased line.
- The customer routers (called data terminal equipment [DTE] in Frame Relay) use Frame Relay data link protocols.
- The Frame Relay service provider makes this promise: to deliver Frame Relay frames to the correct other customer router (based on its permanent virtual circuit [PVC] data-link connection identifier [DLCI]).
- The service is private, in that frames sent by customer A will not be sent to routers owned by customer B.
- The Frame Relay provider can use any technology they want to use inside their network, so figures will likely show a cloud in the middle.

Figure 15-2 reinforces a few of these key comparison points.

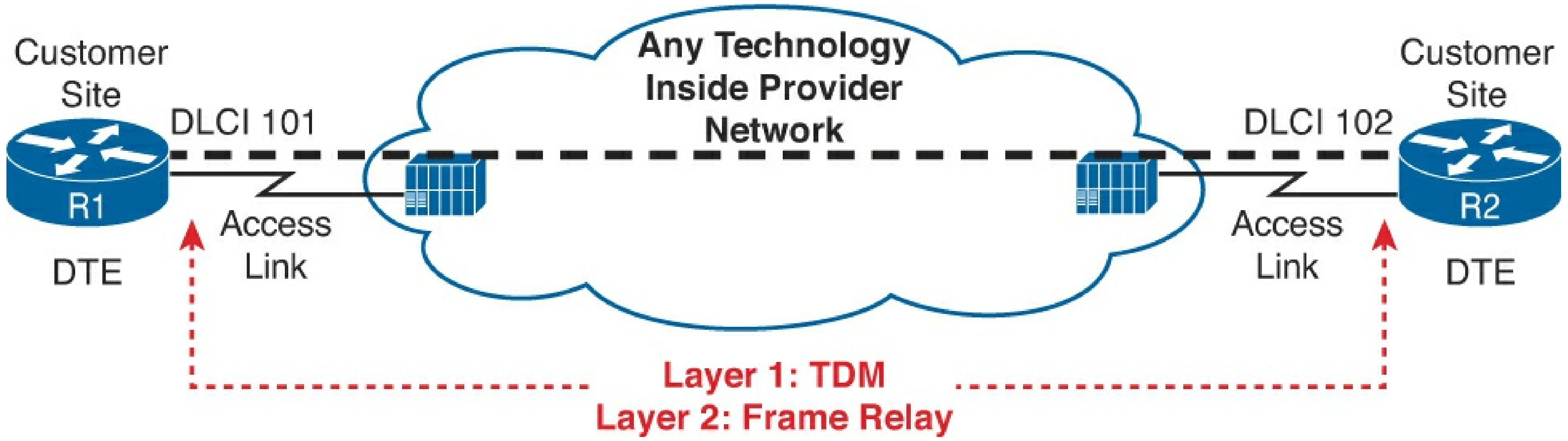

Customer Site
DLCI 101
R1
DTE
Access Link
Any Technology Inside Provider Network
Customer Site
DLCI 102
R2
DTE
Access Link
Layer 1: TDM
Layer 2: Frame Relay

Figure 15-2. Common Items Used to Identify Frame Relay WANs

Ethernet WANs

As a technology, Ethernet began life as a LAN technology only, mainly because Ethernet distance limitations made it impractical for creating the longer links in WAN services. Over time, fiber-based Ethernet Layer 1 standards kept improving, both in speed and in distance. The result: WAN services providers can and do use Ethernet links to offer WAN services, both on the edge with customer access links, and in the core of the provider's network.

One particular Ethernet-based private WAN service uses has a similar model as Frame Relay. The access links use Ethernet standards instead of leased lines, and the routers use Ethernet data link protocols rather than Frame Relay. The routers can send Ethernet frames to each other over the WAN. However, this Ethernet WAN service does not define a concept like PVCs. Figure 15-3 shows the general idea.

Key Topic

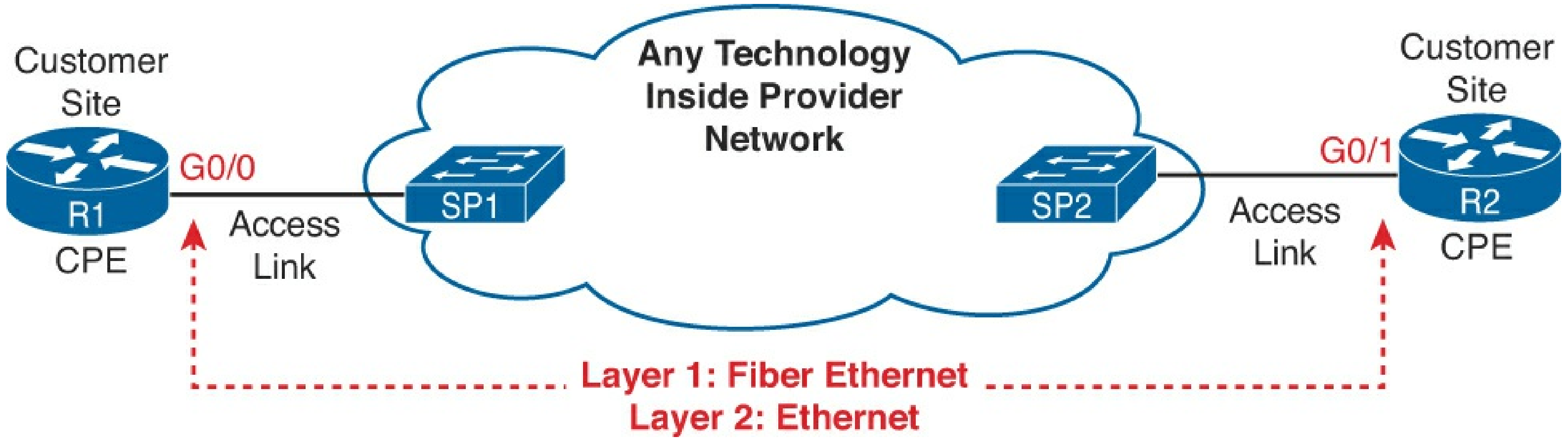

Customer Site
G0/0
R1
CPE
Access Link
Any Technology Inside Provider Network
SP1
SP2
Customer Site
G0/1
R2
CPE
Access Link
Layer 1: Fiber Ethernet
Layer 2: Ethernet

Figure 15-3. Ethernet WAN Service in a Direct Comparison to Frame Relay

The Ethernet WAN service shown in Figure 15-3 can go by many names. This book tends to use the same names mentioned in the associated Cisco courses, namely Ethernet over MPLS (EoMPLS) and the more generic term Ethernet WAN. Other terms for the different kinds of Ethernet WAN services include Metropolitan Ethernet (MetroE) and Virtual Private LAN Service (VPLS). Finally, the term *Ethernet emulation* emphasizes the fact that the provider emulates (acts like) a big Ethernet network but that the provider can use any technology to create the service.

The figure shows one way to think about Ethernet WAN services, with an emphasis on how it is similar to Frame Relay. Certainly, Ethernet WAN services support much faster speeds, with Frame Relay usually using no faster than the 44 Mbps or so of a T3 link, whereas Ethernet WAN services support 100-Mbps or 1-Gbps Ethernet. The following list summarizes some of the key similarities and differences between an Ethernet WAN service and Frame Relay:

Key Topic

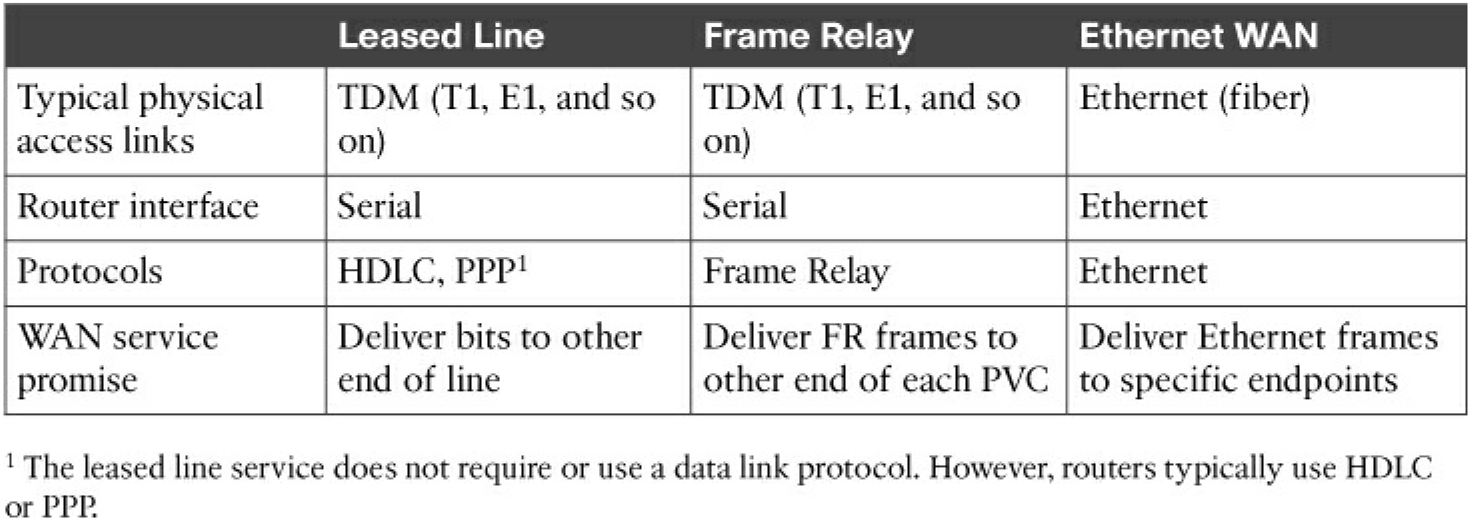
- The access links use any *Ethernet* physical layer standard, but usually some fiber-optic standard to take advantage of the longer cable lengths.
- The customer routers (or LAN switches) will use some kind of Ethernet interface, not a serial interface.
- The customer routers (or LAN switches) use *Ethernet data link* protocols.
- The figure will not show DLCIs, but may show MAC addresses on the WAN.
- The figure may show Ethernet switches inside the Provider's cloud.

- Private, for the same reasons as leased lines and Frame Relay.
- The Ethernet WAN provider can use any technology they want to use inside their network, so figures will likely show a cloud in the middle.

Table 15-3 summarizes the key comparison points between the three WAN technologies discussed so far in this chapter.

Key Topic

Table 15-3. Key Comparison Points for Ethernet WAN, Frame Relay, and Leased Lines



	Leased Line	Frame Relay	Ethernet WAN
Typical physical access links	TDM (T1, E1, and so on)	TDM (T1, E1, and so on)	Ethernet (fiber)
Router interface	Serial	Serial	Ethernet
Protocols	HDLC, PPP[1]	Frame Relay	Ethernet
WAN service promise	Deliver bits to other end of line	Deliver FR frames to other end of each PVC	Deliver Ethernet frames to specific endpoints

[1] The leased line service does not require or use a data link protocol. However, routers typically use HDLC or PPP.

MPLS

Multiprotocol Label Switching (MPLS) follows some ideas similar to both Frame Relay and Ethernet WANs. However, like Ethernet WANs, many types of MPLS WAN services exist, so to nail one down, just to get the general idea, this section talks about one specific use of MPLS, called MPLS VPNs.

MPLS VPN services follow a familiar private WAN model, with a customer connecting sites to an MPLS cloud, and the cloud forwarding data to all that customer's sites connected to the cloud. To keep the data private, as usual, for two unrelated customers A and B, MPLS promises not to forward A's data to B's routers and vice versa.

Many facts make MPLS VPNs different from other WAN services, but the biggest difference is that the service promises to deliver the customer's IP packets between sites, instead of delivering bits (leased lines) or delivering data link frames (Frame Relay and Ethernet WAN). Basically, to the customer, the MPLS network acts much like an IP network, routing the customers IP packets between sites.

Figure 15-4 shows the idea. Customer B connects four routers, B1 through B4, to an MPLS service. Router B3 forwards an IP packet into the MPLS service (Step 1). The MPLS service somehow (details not listed here) forwards that IP packet to the other side of the MPLS service. The service then forwards the IP packet out the access link to the correct customer router, B4 in this case (Step 3).

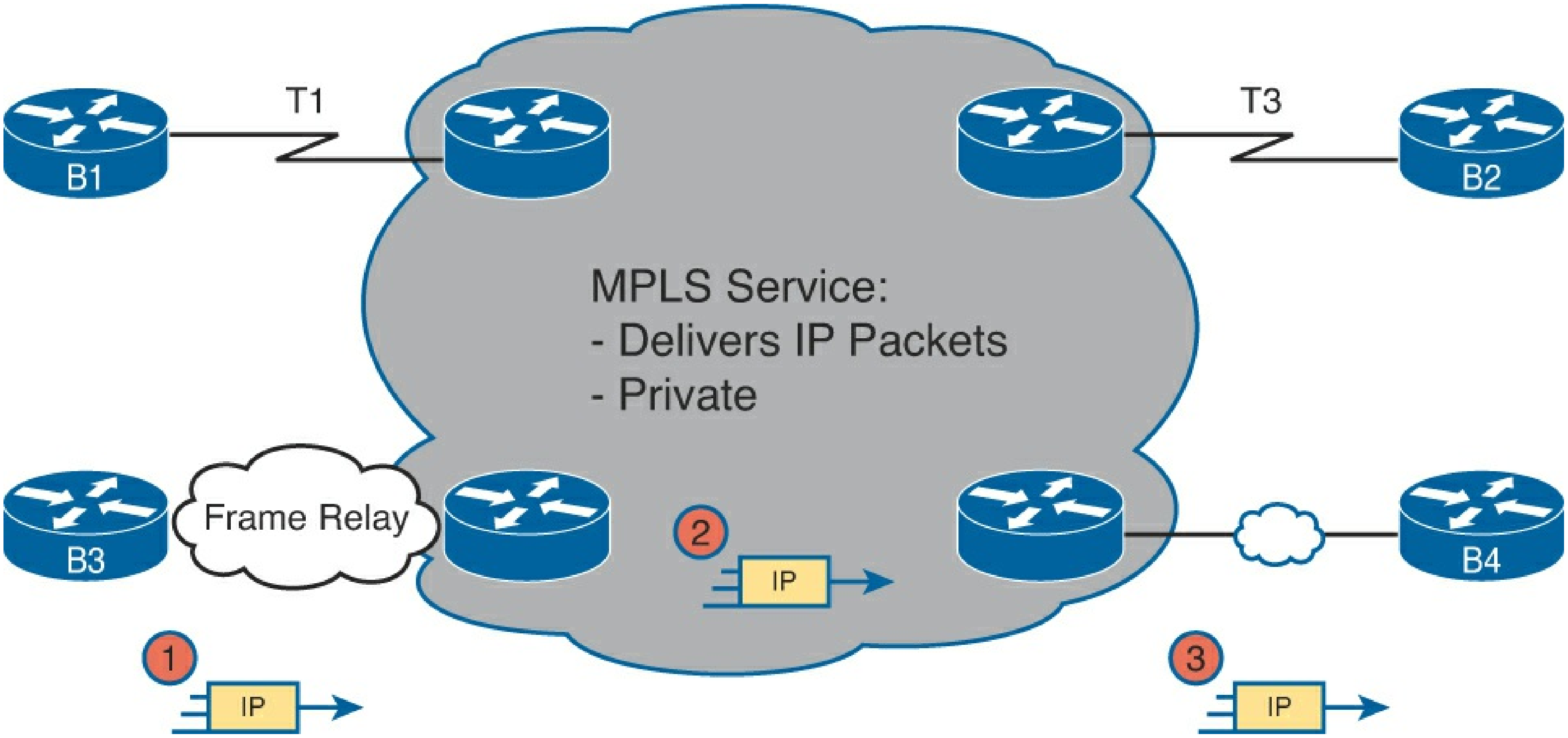


Figure 15-4. MPLS WAN (MPLS VPN) Service Forwarding IP Packets

MPLS has much more flexibility than some other WAN services as a side effect of forwarding IP packets. MPLS can support pretty much any kind of access link that supports IP packets, like the links shown in Figure 15-4. In fact, while Frame Relay has grown less popular in this century, you can still find it in many networks in use as an access link into an MPLS service, as shown in Figure 15-4.

Of the WAN services discussed so far in this chapter, MPLS has the most similarities with Frame Relay and Ethernet WANs. Table 15-4 compares these three options, focusing on the key differences.

Key Topic

Table 15-4. Key Comparison Points for Ethernet WAN, Frame Relay, and MPLS

	MPLS	Frame Relay	Ethernet WAN
Physical access links	Any that support IP	TDM (T1, E1, and so on)	Ethernet (fiber)
Router interface	Any that support IP	Serial	Ethernet
Protocols	Any that support IP	Frame Relay	Ethernet
WAN service promise	Deliver IP packets	Deliver FR frames	Deliver Ethernet frames

VSAT

Finally, note that all the private WAN services discussed so far in this chapter happen to use some kind of cabling. However, in some cases, the locations that need a WAN connection are in places where no service provider offers a WAN service. Maybe the sites are in very remote geographies, on islands where the population is too small to justify expensive underwater cabling, or maybe the terrain just does not allow for cables to be run.

In these cases, a company can create a private WAN using satellite communications and VSAT terminals. VSAT, or very small aperture terminal, refers to a type of satellite dish like the ones you see used for satellite TV from the home, usually about 1 meter in width. The VSAT dish sits outside, pointed at a specific satellite, and is cabled to a special router interface, with the router inside the building. Figure 15-5 shows an example, with the VSAT dishes on the roofs of the buildings.

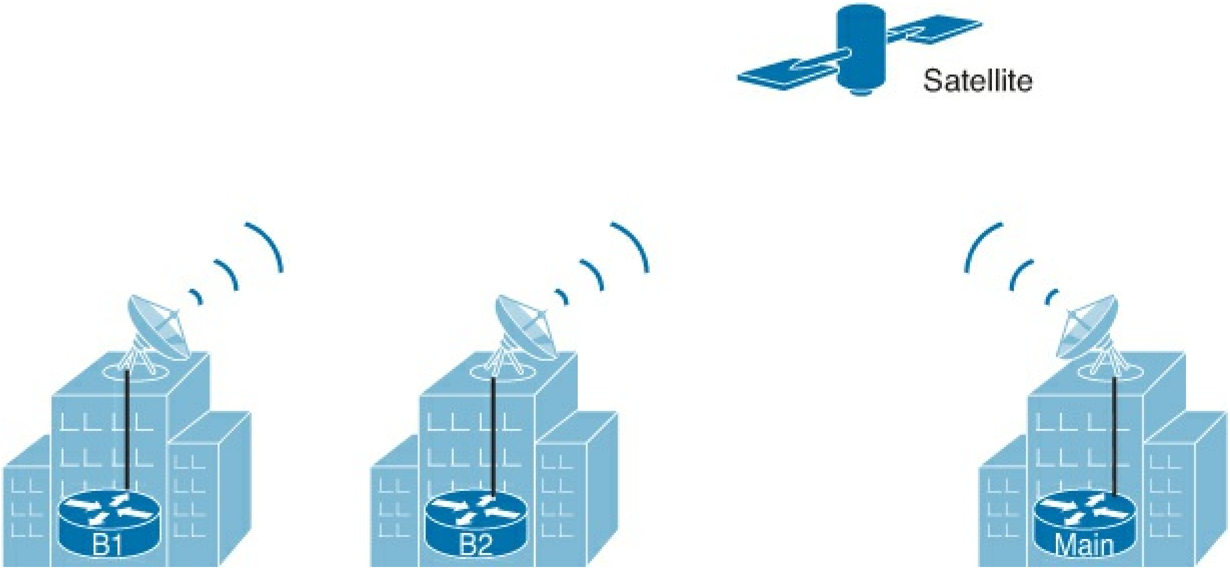


Figure 15-5. VSAT

Using VSATs creates a private WAN somewhat like using leased lines while meeting an important need: connectivity to locations where connectivity is difficult.

Public WANs and Internet Access

To build the Internet, an Internet service provider (ISP) needs links to other ISPs and links to the ISP's customers. The Internet core connects ISPs using a variety of high-speed technologies. Internet access links connect an ISP to each customer, again with a wide variety of technologies. For these customer access links, the technologies need to be inexpensive so that a typical consumer can afford to pay for the service.

Some WAN technologies happen to work particularly well as Internet access technologies. In fact, several use the same telephone line installed into most homes by the phone company so that the ISPs do not have to install additional cabling. Others use the cable TV cabling, whereas others use wireless.

This section briefly touches on several WAN technologies and how they are used to access the Internet. This section ends with a slight tangent to discuss the configuration of one related protocol, called PPP over Ethernet (PPPoE).

Internet Access (WAN) Links

Each WAN technology may be used to build both public and private WANs; some are just a more natural fit for one or the other. However, just to be complete, note that all the WAN technologies discussed in the first half of the chapter happen to work just fine as Internet access technologies, particularly for businesses. Businesses often use TDM serial links, Frame Relay, Ethernet WAN services, or even an MPLS service to access the Internet. Figure 15-6 shows a few of these, just as a visual reminder of these options.

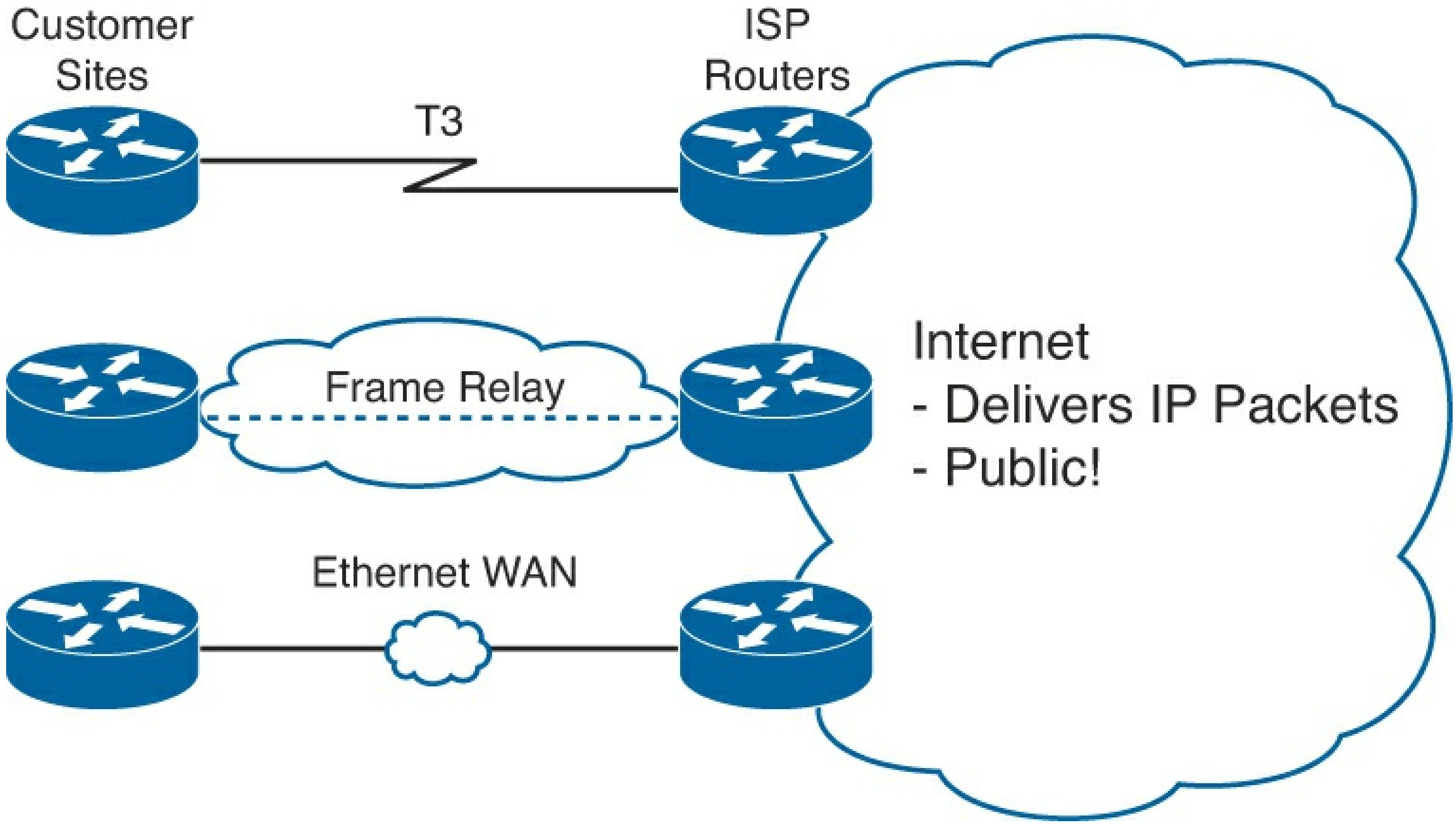


Figure 15-6. Three Examples of Internet Access Links for Companies

Dial Access with Modems and ISDN

The next two Internet access technologies require us to think back to the early days of the Internet for some perspective. The Internet had many booming growth periods over time, but one such period took off in the very early 1990s, when commercial traffic was beginning to drive huge growth in the Internet.

Back in those early days of the Internet, for consumers, most people accessed the Internet using dial-up. That is, they used their analog phone line and an analog modem and basically placed a phone call to an ISP.

As a brief bit of background, when using a home telephone line, a phone call creates an electrical circuit that uses analog signals. Computers use digital signals; so to use an analog circuit, something had to convert from digital to analog. The solution: an analog modem.

Analog modems would sit at each end of the call—one at the customer site, and one at the ISP. To send the digital data from the customer's PC or router, the modem would modulate, or convert, the digital signal to an analog signal. The sending modem then transmits the analog signals to the receiving modem, which would then demodulate the analog back into the original digits. (The term *modem* comes from the squashing of those two terms together: modulate and demodulate.)

Figure 15-7 shows the general idea, with two examples. One shows a PC with an external modem, meaning that the PC connects to the modem with a cable. The other shows an internal modem. The ISP would then have a matching set of modems, called a modem bank. A phone call to the ISP's phone number would ring to any available modem, allowing a customer to connect to any one of the ISP modems and be connected to the Internet.

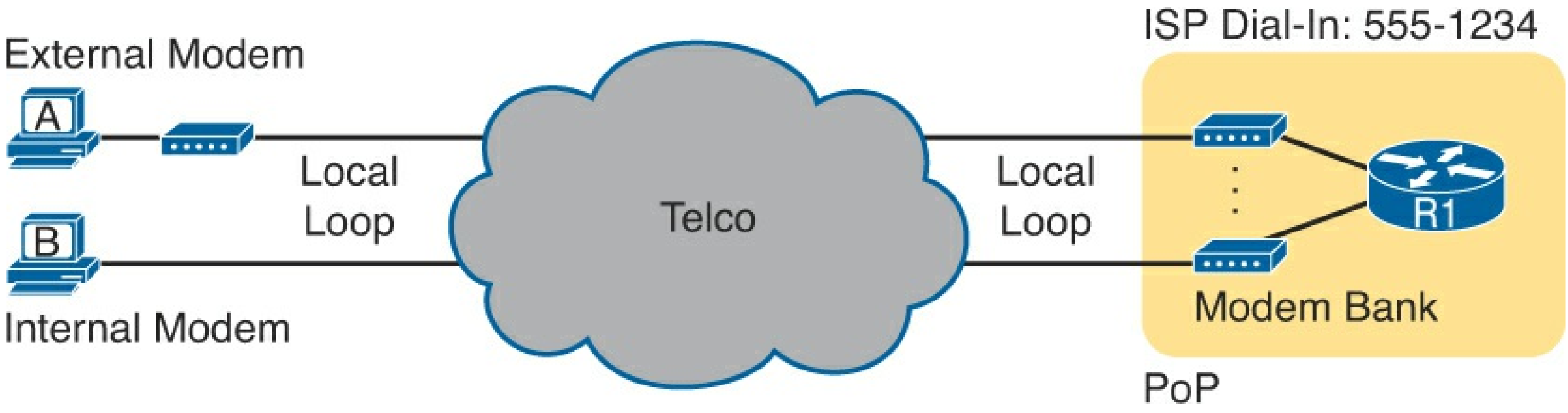


Figure 15-7. Internet Access Using External and Internal Modems

Today, most ISPs refer to this option as *dial access* or simply *dial*. And even though ISPs have used it for decades, most ISPs still offer dial services. Dial can be an inexpensive in some markets and a workable service for people in remote areas where faster Internet access options are not available.

Note

Telcos refer to the telephone cable that runs into a customer's home or business the *local loop*.

Dial access happens to have several cost advantages compared to other consumer Internet access options. The ISP purposefully puts a point of presence (PoP) in most local calling areas, so the phone call to connect to the Internet is free, rather than having a long-distance charge. Also the equipment cost fell pretty quickly over time, so the price to get started is relatively low. And in many markets, almost every home has a home phone line already, so there is no need to spend more for the physical access link. As a result, the only added cost is the fee to the ISP to allow access into the Internet.

Of course, there are negatives, too. You can either surf the Internet or make a voice phone call, but not both. To use the Internet, you had to make a phone call first, so the Internet was not "on" all the time. But the speed is the biggest issue, with a fast modem having a bit rate over the line of only 56 Kbps, an incredibly slow speed by today's standards.

Over time, the telcos of the world set out to improve over the analog modem option. One early improvement used an entirely new technology called Integrated Services Digital Network (ISDN). ISDN allowed some of the same cost advantages as analog modems, but with faster speeds. For instance:

- ISDN used the same local loop (local phone line), which most people already had.
- ISDN required the equivalent of a phone call to the ISP, just like with analog modems.
- ISPs already had a PoP in each local calling areas to support analog modems, so these ISDN calls would not require any long-distance charges.

The big advantage of ISDN was speed. ISDN uses digital signals over the local loop, instead of analog. In addition, it supports two calls at the same time, each at 64 Kbps, over that one local loop phone line. Both calls (channels) could be dialed to the ISP, for a 128-Kbps Internet service. Or, the user could make one voice phone call and have one 64-Kbps Internet connection at the same time. ISDN did cost a little more—you had to pay the telco for the upgraded ISDN service—but you got concurrent Internet and voice, plus better speed than analog modems.

Figure 15-8 shows some particulars of ISDN. The consumer side of an ISDN used a line called a Basic Rate Interface (BRI), which has the two 64-Kbps channels for user traffic. Physically, the connection used some type of ISDN-aware device, often referred to as an ISDN modem, taking the place of an analog modem.

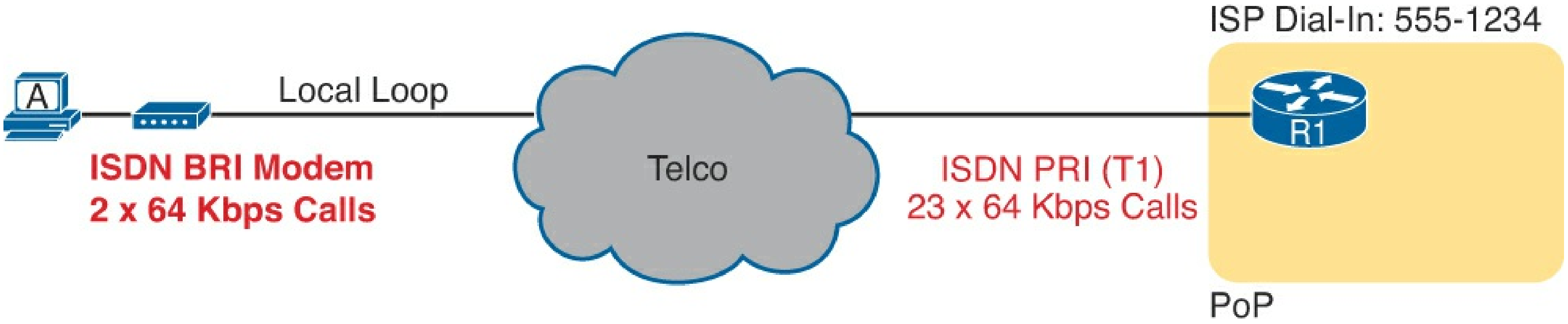
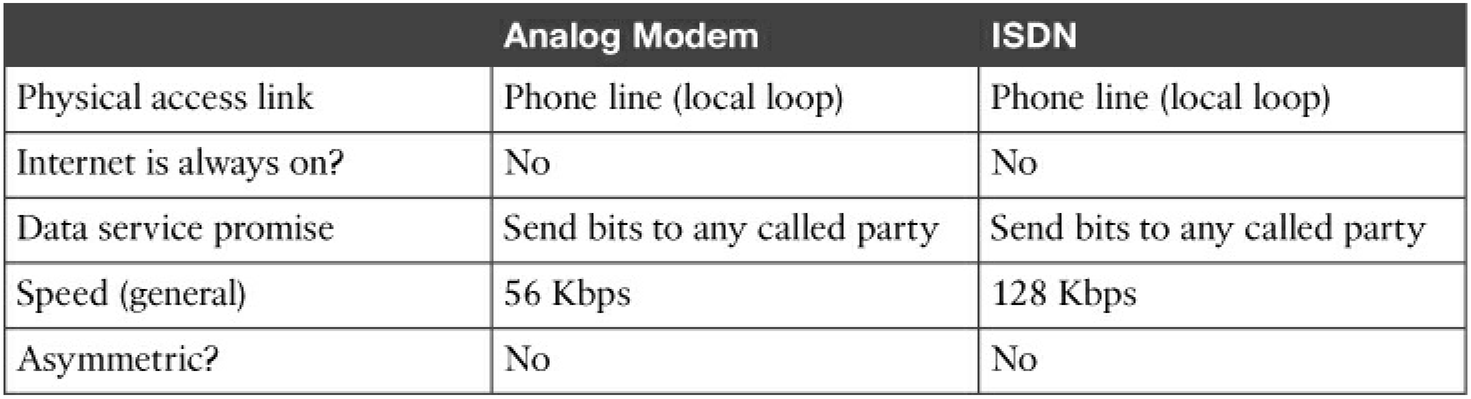


Figure 15-8. Typical ISDN Connection

The ISP side of the connection could use many different technologies, as well, including an ISDN technology called a Primary Rate Interface (PRI). This technology turned a T1 physical line into 23 ISDN channels ready to accept those ISDN calls, as shown on the right.

Both analog modems and ISDN filled big needs for Internet access in the early days of the Internet. Using existing phone lines that people already paid for anyway was a great business model. However, their relatively slow speeds led to innovation to faster Internet access—both from the telcos of the world and their emerging competitors of the time, the cable TV companies. Table 15-5 summarizes a few of the key comparison points so far.

Table 15-5. Comparison of Internet Access Technologies



	Analog Modem	ISDN
Physical access link	Phone line (local loop)	Phone line (local loop)
Internet is always on?	No	No
Data service promise	Send bits to any called party	Send bits to any called party
Speed (general)	56 Kbps	128 Kbps
Asymmetric?	No	No

Digital Subscriber Line

In the consumer Internet access space, the big speed breakthrough happened with the introduction of the digital subscriber line (DSL). It represented a big technological breakthrough in terms of raw speed. These faster speeds also changed how people could use the Internet because many of today's common applications would be unusable at analog modem and ISDN speeds.

As with ISDN, telcos greatly influenced the creation of DSL. As a technology, DSL gave telcos a way to offer much faster

Internet access speeds. As a business, DSL gave telcos a way to offer a valuable high-speed Internet service to many of their existing telephone customers, which created a great way for telcos to make money.

As a technology, DSL works much differently than both analog modems and ISDN. To see how, first focus on the home side of the DSL connection, as shown on the left side of Figure 15-9. The phone can do what it has always done: plug into a phone jack and send analog. For the data, a DSL modem connects to a spare phone outlet. The DSL modem sends and receives the data, as digital signals, at higher frequencies, over the same local loop, even at the same time as a telephone call.

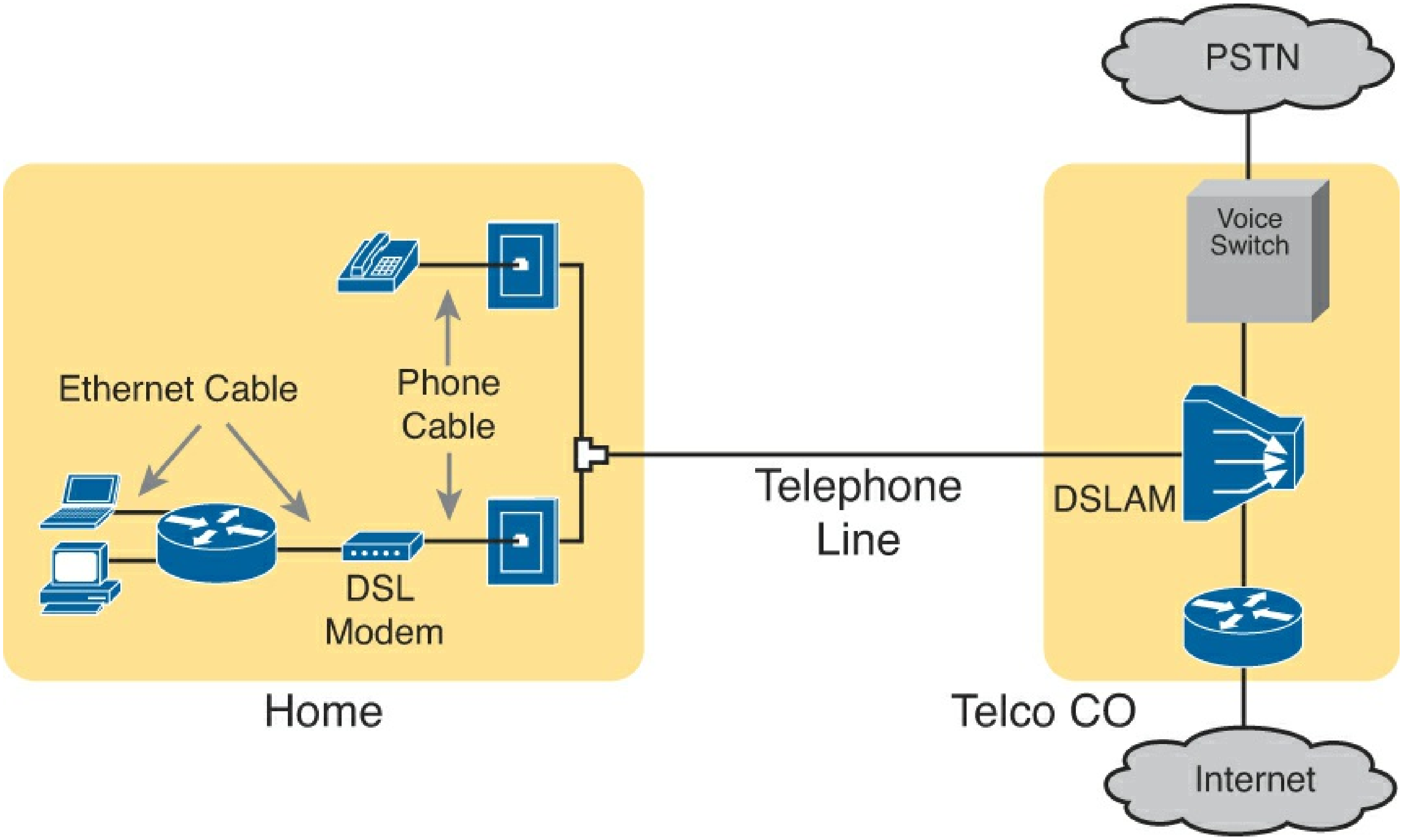


Figure 15-9. Wiring and Devices for a Home DSL Link

Because DSL uses analog (voice) and digital (data) signals on the line, the telco has to somehow split those signals on the telco side of the connection. To do so, the local loop must be connected to a DSL access multiplexer (DSLAM) located in the nearby telco central office (CO). The DSLAM splits out the digital data over to the router on the lower right, which completes the connection to the Internet. The DSLAM also splits out the analog voice signals over to the voice switch on the upper right.

DSL has many advantages, particularly compared to the analog and ISDN dial options. For instance, asymmetric DSL (ADSL), in which many of the consumer DSL offerings is based, routinely supports speeds in the 5-Mbps range, and up to 24 Mbps in ideal conditions. Also, ADSL supports asymmetric speeds, which better matches most consumer traffic models. Asymmetric speeds means that the transmission speed toward the home (downstream) is much faster than the transmissions toward the ISP (upstream). Asymmetric speeds work better for consumer Internet access from the home because clicking a web page sends only a few hundred bytes upstream into the Internet but may trigger many megabytes of data to be delivered downstream to the home.

Of course, every option, including DSL, has some negatives. DSL may cost more than dial—probably worth the money to most people, but it does usually cost more. Also, as a technology, DSL has limitations. DSL works only at certain distances from the CO to the home, and the speeds degrade within the longer of the working cabling distances. So, the quality of the service, or availability of the service at all, may be impacted simply by the distance between the home and the CO.

Cable Internet

Analog modems, ISDN, and DSL all use the local link (telephone line) from the local telco. This next option instead uses the cabling from what has become the primary competitor to the telco in most markets: the cable company.

Cable Internet creates an Internet access service which, when viewed generally rather than specifically, has many similarities to DSL. Like DSL, cable Internet takes full advantage of existing cabling, using the existing cable TV (CATV) cable to send data. Like DSL, cable Internet uses asymmetric speeds, sending data faster downstream than upstream, which works well for most consumer locations. And like DSL, cable Internet still allows the normal service on the cable (cable TV), at the same time as the Internet access service is working.

Cable Internet also uses the same general idea for in-home cabling as DSL, just using CATV cabling instead of telephone cabling. The left side of Figure 15-10 shows a TV connected to the CATV cabling, just as it would normally connect. At another cable outlet, a cable modem connects to the same cable. The Internet service flows over one frequency, like yet another TV channel, just reserved for Internet service.

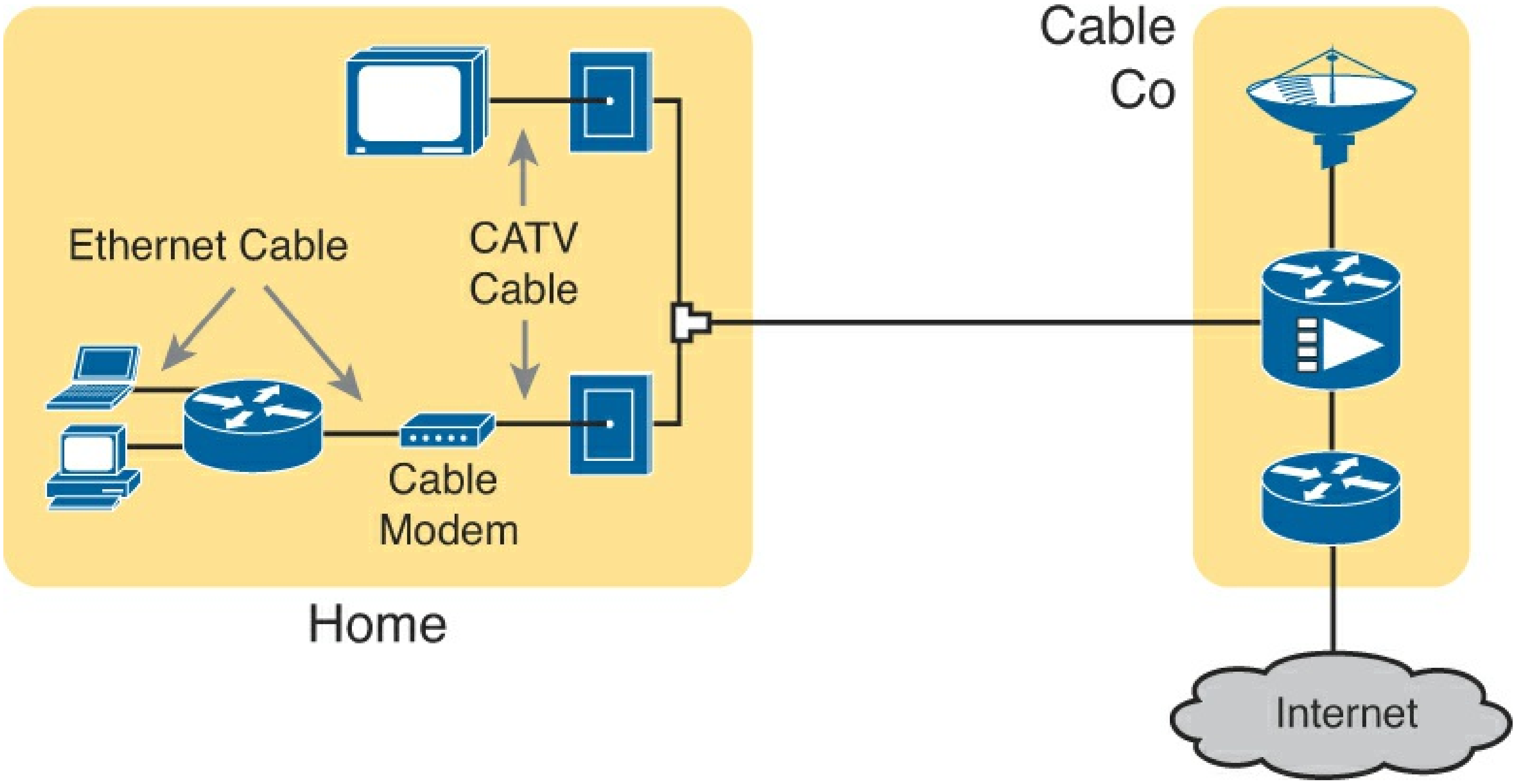


Figure 15-10. Wiring and Devices for a Home Cable Internet Link

Similar to DSL, on the CATV company side of the connection (on the right side of the figure), the CATV company must split out the data and video traffic. Data flows to the lower right, through a router, to the Internet. The video comes in from video dishes for distribution out to the TVs in people's homes.

Cable Internet service and DSL directly compete in both the consumer and business markets. Generally speaking, while both offer high speeds, cable Internet usually runs at faster speeds than DSL, with DSL providers often keeping their prices a little lower to compete. Both support asymmetric speeds, and both provide an "always on" service, in that you can communicate with the Internet without the need to first take some action to start the Internet connection.

Table 15-6 summarizes some of the key comparison points again.

Key Topic

Table 15-6. Comparison of Internet Access Technologies

	Analog Modem	ISDN	DSL	Cable
Physical access link	Phone line (local loop)	Phone line (local loop)	Phone line (local loop)	CATV cable
Internet is always on?	No	No	Yes	Yes
Data service promise	Send bits to any called party	Send bits to any called party	Send all data to the ISP	Send data to the ISP
Speed (general)	56 Kbps	128 Kbps	10s of Mbps	10s of Mbps
Asymmetric?	No	No	Yes	Yes

Mobile Phone Access with 3G/4G

Many of you reading this book have a mobile phone that has Internet access. That is, you can check your email, surf the web, download apps, and watch videos. Most social media addicts rely on their mobile phones, and the Internet access built in to that phone, for most of their tweets and the like. This section touches on the big concepts behind the Internet access technology behind those mobile phones.

Mobile phones use radio waves to communicate through a nearby mobile phone tower. The phone has a small radio antenna, and the provider has a much larger antenna sitting at the top of a tower somewhere within miles of you and your phone. Phones, tablet computers, laptops, and even routers (with the correct interface cards) can communicate through to the Internet using this technology, as represented in Figure 15-11.

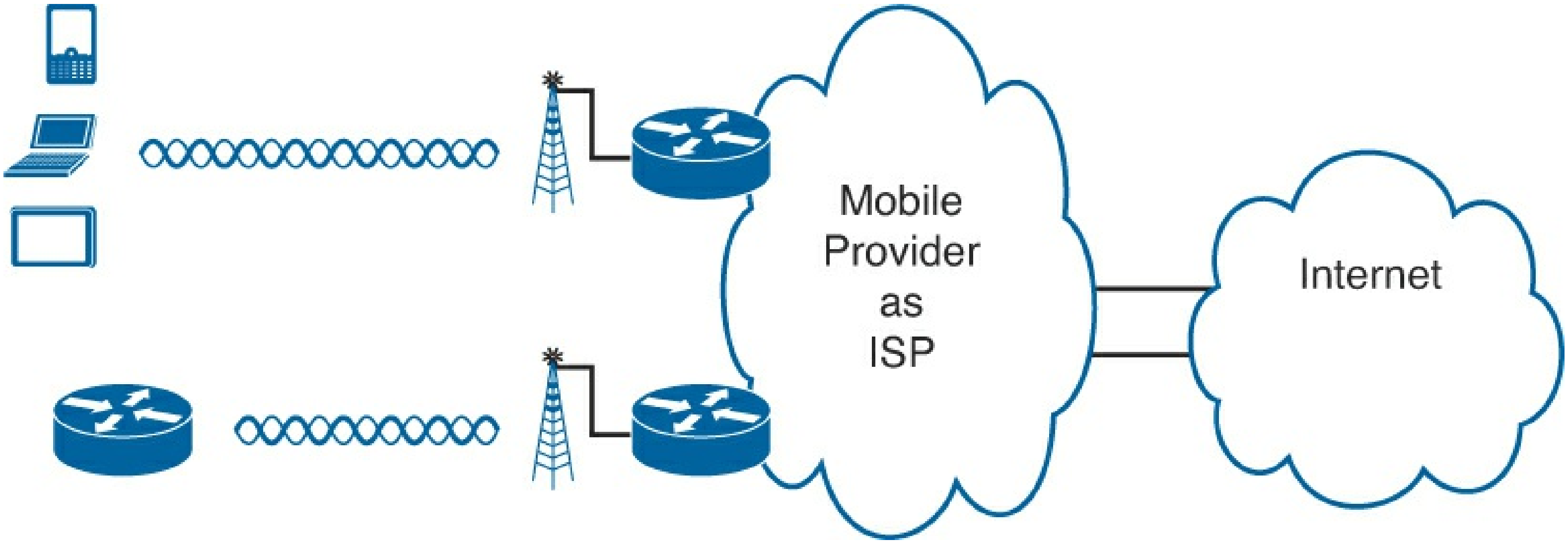


Figure 15-11. Wireless Internet Access Using 3G/4G Technology

The mobile phone radio towers also have cabling and equipment, including routers. The mobile provider builds their own IP network, much like an ISP builds out an IP network. The customer IP packets pass through the IP router at the tower into the mobile provider's IP network and then out to the Internet.

The market for mobile phones and wireless Internet access for other devices is both large and competitive. As a result, the mobile providers spend a lot of money advertising their services, with lots of names for one service or the other. Frankly, it can be difficult to tell what all the marketing jargon means, but a few terms tend to be used throughout the industry:

Key Topic

Wireless Internet: A general term for Internet services from a mobile phone or from any device that uses the same technology.

3G/4G Wireless: Short for third generation and fourth generation, these terms refer to the major changes over time to the mobile phone companies' wireless networks.

LTE: Long-Term Evolution, which is a newer and faster technology considered to be part of fourth generation (4G) technology.

The takeaway from all this jargon is this: When you hear about wireless Internet services with a mobile phone tower in the picture—whether the device is phone, tablet, or PC—it is probably a 3G, 4G, or LTE wireless Internet connection.

PPP over Ethernet

To finish off this chapter, this final topic takes a brief departure away from listing WAN technologies, instead discussing one technology overlaid on top of some DSL connections: PPP over Ethernet (PPPoE).

PPP over Ethernet Concepts

First, think back to Chapter 12's discussion of PPP and CHAP for a moment. PPP is one of those frankly boring data link protocols used on point-to-point links, whereas Challenge Handshake Authentication Protocol (CHAP) is that part of PPP that allows authentication. PPP can be used on serial links, which includes those links created with dial-up analog and ISDN modems. For instance, the link from a dial user to an ISP, using analog modems, likely uses PPP today. Figure 15-12 shows a basic representation of that analog dial connection with PPP.

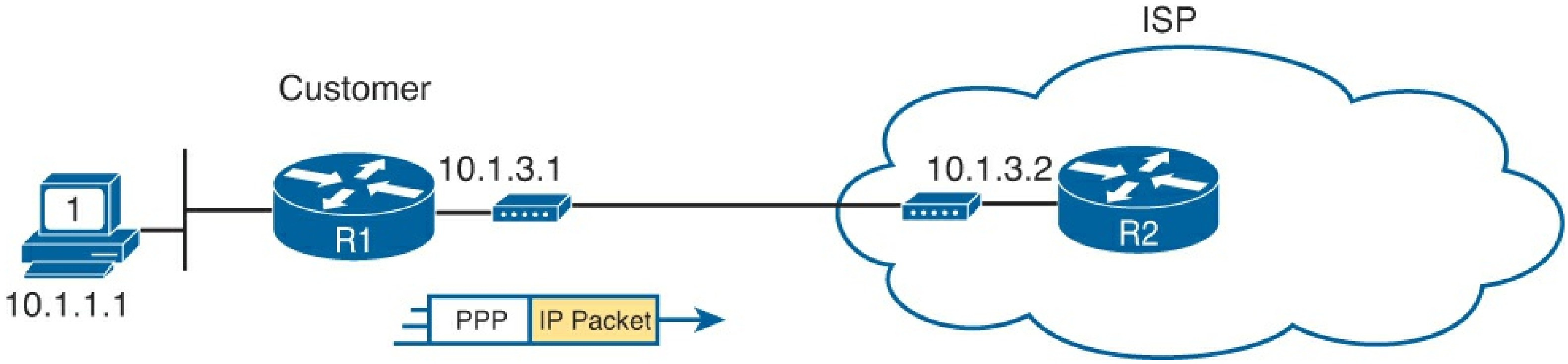


Figure 15-12. PPP Frames Between Routers over a Dial Connection to an ISP

ISPs used PPP as the data link protocol for a couple of reasons. First, PPP supports a way to assign IP addresses to the other end of the PPP link. ISPs can use PPP to assign each customer one public IPv4 address to use. But more important for this discussion is that PPP supports CHAP, and ISPs may want to use CHAP to authenticate customers. Then, when using CHAP to authenticate, ISPs could check accounting records to determine whether the customer's bill was paid before letting the customer connect to the Internet.

Now, think back a bit to the history of some of these Internet access technologies. The following technologies came to market in the following order, with varying support for PPP:

1. Analog modems for dial-up, which could use PPP and CHAP
2. ISDN for dial-up, which could use PPP and CHAP
3. DSL, which did not create a point-to-point link and could not support PPP and CHAP

So, telcos and ISPs liked DSL, but some ISPs still wanted their PPP! However, the customer often used an Ethernet link between the customer PC or router and the DSL modem (see earlier Figure 15-9). That Ethernet link only supported Ethernet data link protocols, and not PPP.

What ISPs needed was a way to create the equivalent of a PPP connection between the customer router and the ISP router over the various technologies used on the various DSL connections. As you might guess, several new protocols were created, including one that allowed the sending of PPP frames encapsulated inside Ethernet frames: the PPP over Ethernet (PPPoE) protocol.

PPPoE basically creates a tunnel through the DSL connection for the purpose of sending PPP frames between customer router and the ISP router, as shown in Figure 15-13. DSL does not create a single point-to-point link between these routers. With PPPoE (and related protocols), the routers logically create such a tunnel. From one perspective, the routers create and send PPP frames, as if the link were a dial link between the routers. But before sending the frames over any physical link, the routers encapsulate the frames inside various headers, shown generically in the figure as a tunnel header.

Key Topic

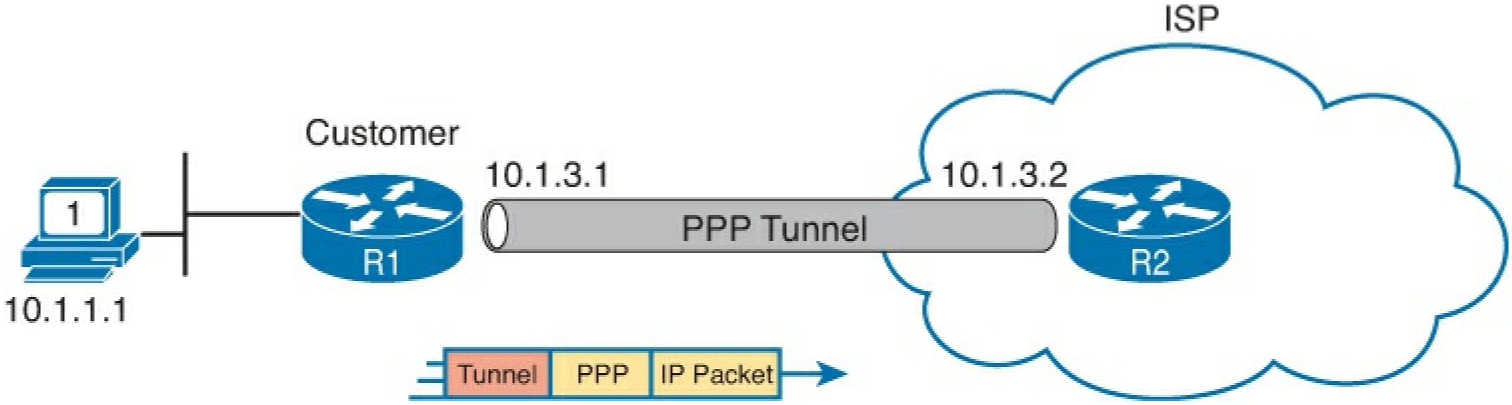


Figure 15-13. Tunneling Concept to Create a PPP Link over Ethernet

Note

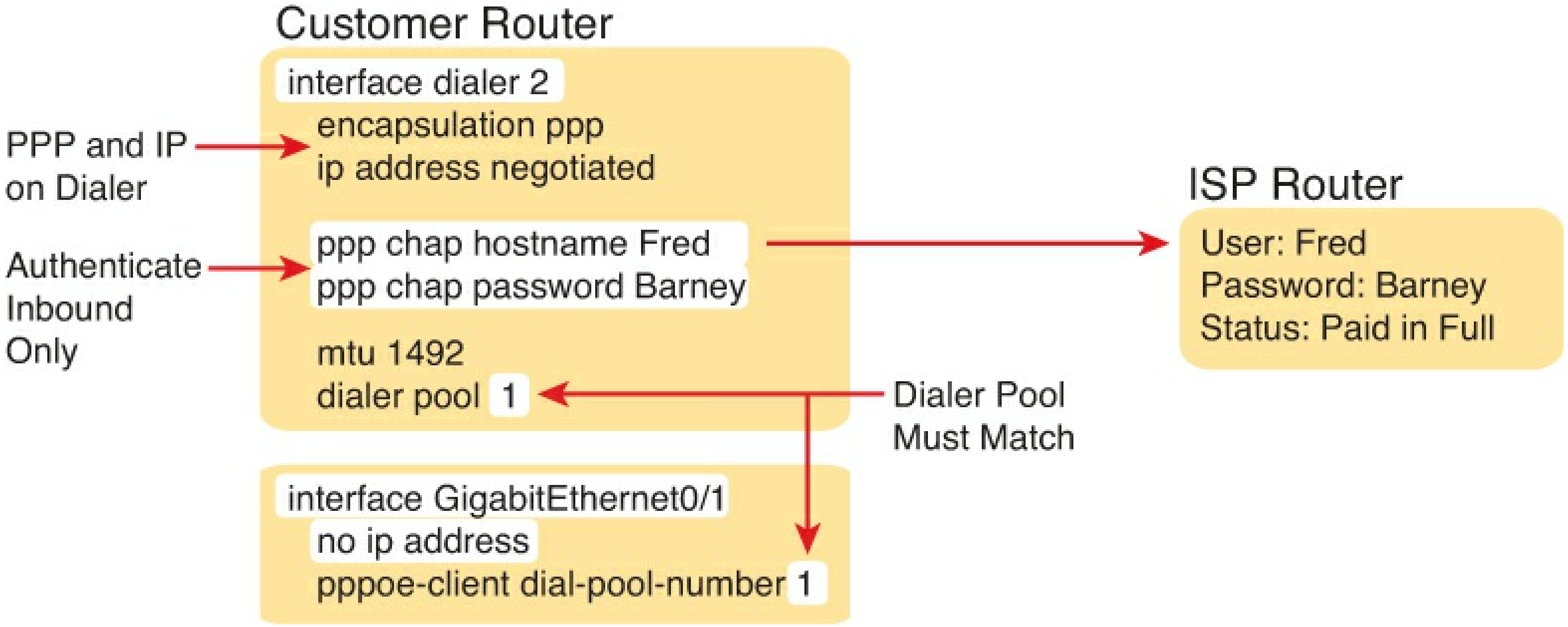
For the purposes of this chapter, the specifics of the tunnel header do not matter. However, literally, the PPPoE tunnel header in this case has a typical Ethernet header, a short header defined for PPPoE's use, and then the PPP frame (which includes the IP packet).

PPP over Ethernet Configuration

With the ability to send and receive PPP frames between the routers, the ISP could continue to use the same authentication model as they did with analog and ISDN dial. To make it all work, the client and ISP routers need some new configuration, including PPP configuration. The remainder of this topic looks at the big picture of the client side configuration.

For this configuration, take a slightly different approach. Imagine that you will see a sample configuration like the sample shown in Figure 15-14. Then you have to decide which parameters need to match. (Do not worry about building these configurations from scratch.) To begin understanding the configuration, keep the following facts in mind:

- The configuration uses a dialer interface, which is the virtual interface used to create the PPP tunnel. The PPP configuration goes on the dialer interface.
- The physical Ethernet interface that connects to the DSL modem will have a command that both enables PPPoE and links the interface to the dialer interface.
- The PPP CHAP configuration usually defines one-way authentication; that is, the ISP authenticates the customer, as shown in the upcoming example. (The examples in Chapter 12 show two-way authentication.)
- The client can configure a static IP address, but will more likely ask to be assigned a public IP address by the ISP (as shown here).


Customer Router
PPP and IP on Dialer
Authenticate Inbound Only
Dialer Pool Must Match
ISP Router
User: Fred
Password: Barney
Status: Paid in Full

```
interface dialer 2
  encapsulation ppp
  ip address negotiated

  ppp chap hostname Fred
  ppp chap password Barney

  mtu 1492
  dialer pool 1

interface GigabitEthernet0/1
  no ip address
  pppoe-client dial-pool-number 1
```

Figure 15-14. Client Configuration for PPPoE

So, if faced with a sample configuration to review, keep an eye out for the big items in the configuration. For instance, the PPP configuration sits on the dialer interface, not the Ethernet interface. Check the CHAP username and password, which must match the settings on the ISP. Make sure that the **dialer interface** is linked to the Ethernet interface with the **dialer pool** and **pppoe-client** commands, with the same number as noted in the figure. (The dialer interface number itself does not have to match.) And the maximum transmission unit (MTU) should be set down to 1492 (versus the default of 1500) to accommodate the PPPoE headers.

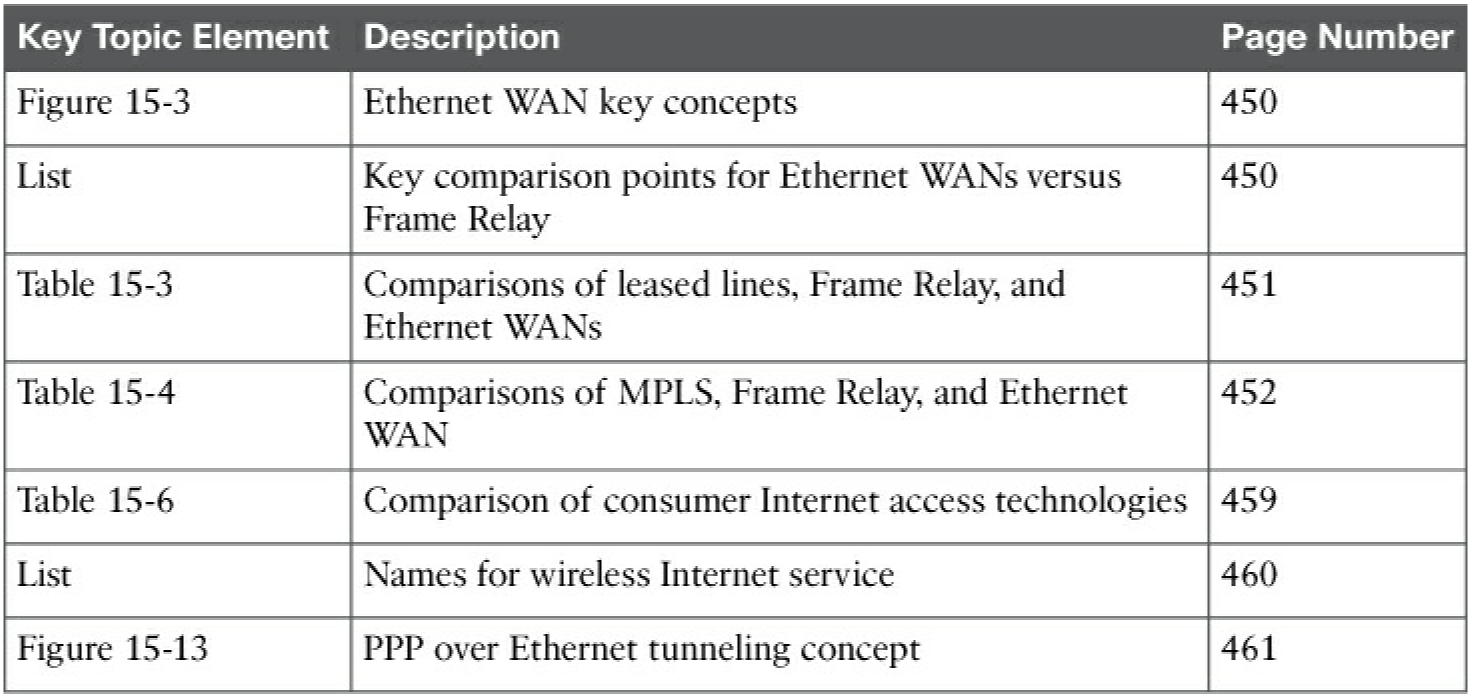
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 15-7 lists these key topics and where each is discussed.

Key Topic

Table 15-7. Key Topics for Chapter 15



Key Topic Element	Description	Page Number
Figure 15-3	Ethernet WAN key concepts	450
List	Key comparison points for Ethernet WANs versus Frame Relay	450
Table 15-3	Comparisons of leased lines, Frame Relay, and Ethernet WANs	451
Table 15-4	Comparisons of MPLS, Frame Relay, and Ethernet WAN	452
Table 15-6	Comparison of consumer Internet access technologies	459
List	Names for wireless Internet service	460
Figure 15-13	PPP over Ethernet tunneling concept	461

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix D, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix E, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Definitions of Key Terms

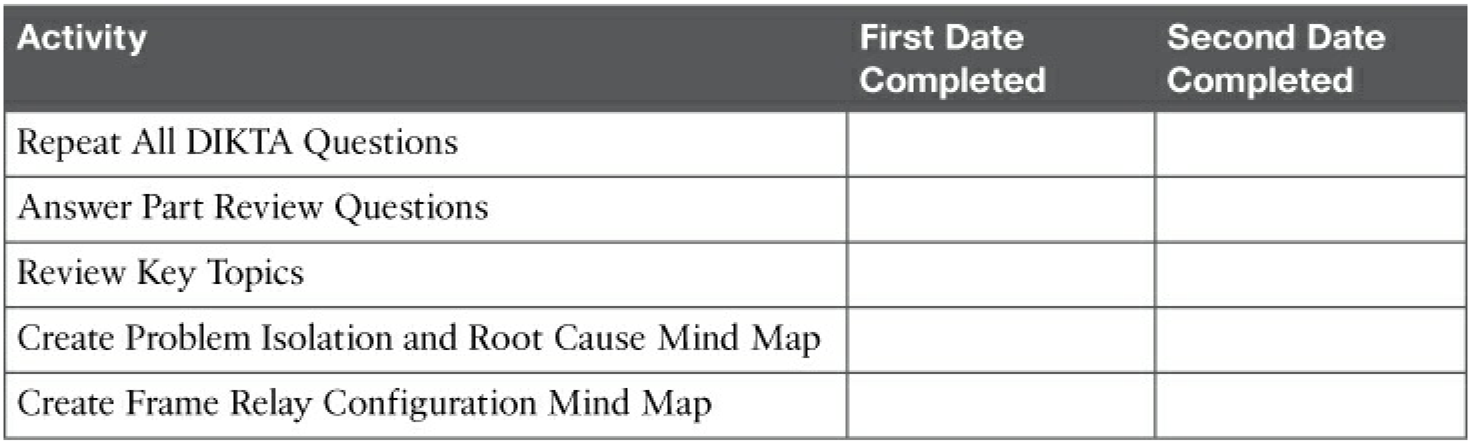
After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22 directs you in how to use these terms for late-stage preparation for the exam.

MPLS
Ethernet WAN
VSAT
analog modem
ISDN
dial access
DSL
cable Internet
3G/4G Internet
PPP over Ethernet

Part IV Review

Keep track of your part review progress with the checklist in Table P4-1. Details about each task follow the table.

Table P4-1. Part IV Part Review Checklist



Activity	First Date Completed	Second Date Completed
Repeat All DIKTA Questions		
Answer Part Review Questions		
Review Key Topics		
Create Problem Isolation and Root Cause Mind Map		
Create Frame Relay Configuration Mind Map		

Repeat All DIKTA Questions

For this task, answer the “Do I Know This Already?” questions again for the chapters in Part I of this book using the PCPT software. See the section “How to View Only DIKTA Questions by Part” in the Introduction to this book to learn how to make the PCPT software show you DIKTA questions for this part only.

Answer Part Review Questions

For this task, answer the Part Review questions for this part of the book using the PCPT software. See the section “How to View Only DIKTA Questions by part” in the Introduction to this book to learn how to make the PCPT software show you DIKTA questions for this part only.

Review Key Topics

Key Topic

Browse back through the chapters and look for the Key Topic icons. If you do not remember some details, take the time to reread those topics.

Create Problem Isolation and Root Cause Mind Map

For this first Part Review mind map, think about troubleshooting serial links and Frame Relay. Think about all the symptoms, whether they are the root cause or whether they help you isolate a problem to get closer to the root cause. Then put them together in a mind map. Basically, if R1 and R2 connect with the same serial link, or the same Frame Relay permanent virtual circuit (PVC), what can prevent them from successfully pinging each other’s IP address? Then organize those into a mind map.

To organize the mind map, start by just listing whatever comes to mind. Then, group the symptoms and root causes. One of the main points is to organize these ideas into your frame of reference, so the organizing of the information is just as important as the individual facts. However, do group the serial link causes into one set and Frame Relay causes in another.

> **Note**
>
> For more information about mind mapping, see the section “About Mind Maps” in the Introduction to this book.

Create Frame Relay Configuration Mind Map

Frame Relay has two big challenges related to the configuration. First, it has three main styles of configuration: using the physical interface, multipoint subinterfaces, and point-to-point subinterfaces. Second, it has many useful default settings.

For this mind map, treat Frame Relay configuration as three topics. For the first, assume the IP addresses and data link connection identifiers (DLCI) will be used on the physical interface. Then list all configuration commands, and list their default values as well. Use a different color for commands whose default value can be used for this branch.

Then, do the same thing for a second branch: multipoint subinterface configurations. Finally, repeat the exercise again for a point-to-point subinterface branch. Include the commands to create the subinterfaces.

At the end, your mind map will repeat most commands three times. However, it should also help you see the differences in the commands used in each style of configuration.

DVD Appendix F, “Mind Map Solutions,” lists sample mind map answers, but as usual, your mind maps can and will look different.

Part V: IP Version 6

Chapter 16: Troubleshooting IPv6 Routing

Chapter 17: Implementing OSPF for IPv6

Chapter 18: Implementing EIGRP for IPv6

Part V Review

As with IPv4, Cisco has organized the IP Version 6 (IPv6) topics for the exams by spreading the topics between the ICND1 and ICND2 exams. For ICND1, Cisco included the basics: addressing, subnetting, routing, router address and static route configuration, as well as basic OSPF configuration. ICND2 then takes the routing protocol topics a little deeper, with more OSPF, adding EIGRP, and with troubleshooting for the routing (forwarding) process and for the routing protocols.

Part V of this book follows the same general approach for IPv6 as the chapters in Parts II and III did for IPv4. Chapter 16 first reviews IPv6 addressing and routing, to the depth of the ICND1 exam, while discussing troubleshooting of those same topics. Chapter 17 takes OSPF Version 3 (OSPFv3) a little deeper, while giving troubleshooting tips as well. Finally, Chapter 18 details a second IPv6 routing protocol, EIGRP for IPv6 (EIGRPv6).

Chapter 16. Troubleshooting IPv6 Routing

This chapter covers the following exam topics:

- **Troubleshooting**
- Identify and correct common network problems
- Troubleshoot and resolve routing issues
  - Routing is enabled
  - Routing table is correct
  - Correct path selection

The first step in troubleshooting any networking technology is to understand what should happen under normal conditions. Then, the troubleshooting process can compare the current network behavior with what should be happening, looking for differences, until the root cause of those differences can be found.

This chapter begins with a review of the ICND1 book's discussion about how IPv6 works normally. Thankfully, IPv6 has many similarities to IPv4, other than the obvious differences in addressing. This section builds on those similarities and summarizes the core features of IPv6 to set the stage for a discussion of troubleshooting IPv6.

The second major section of the chapter examines a variety of problems that can occur in an IPv6 network. All these problems take a part of IPv6 that should work normally and show some issues that prevent that function from working.

"Do I Know This Already?" Quiz

This chapter does not have a "Do I Know This Already Quiz" because the chapter focuses on troubleshooting. The troubleshooting chapters include several hints and tips that show how to solve particular problems; so even if you know the topics well, a quick reading of the chapter should be useful. For these reasons, the troubleshooting chapters do not include a "Do I Know This Already?" quiz. However, if you feel particularly confident about the IPv6 features covered in this book and in the *Cisco CCENT/CCNA ICND1 100-101 Official Cert Guide*, feel free to move to the "Exam Preparation Tasks" section near the end of this chapter to bypass the majority of the chapter.

Foundation Topics

Normal IPv6 Operation

To be ready to troubleshoot an IPv6 problem, you have to remember many facts about how IPv6 works. Thankfully, many IPv6 concepts work much like IPv4, but there are enough differences to make it worth the time to review IPv6 as an end to itself. This first section of the chapter reviews the details of IPv6, condensing five chapters of the ICND1 book into one concise review section.

This first section, from this page up to the heading "IPv6 Troubleshooting," repeats concepts discussed in the ICND1 book. If you are using both books, you might need to go back and review, or you might be ready to skip this section, as suggested here:

Skip to "IPv6 Troubleshooting": If you know IPv6 well, right now, skip ahead. For instance, maybe you are following a reading plan under which you just finished reading the ICND1 book's IPv6 chapters and the material is fresh in your mind. Just know that this first section introduces no new concepts as compared to the ICND1 book's IPv6 chapters.

Read this section: If you remember some of your IPv6 knowledge, but not all, this section is built for you. Keep reading!

Go back and review the ICND1 book: If you have not thought about IPv6 for quite a while, and you really do not remember much at all about it, you might be better off reviewing the IPv6 chapters in the ICND1 book first.

So, what is in this section? It hits the highlights of IPv6. Of course, it reviews IPv6 unicast addressing and subnetting. This section also discusses host IPv6 configuration, including stateless address autoconfiguration (SLAAC) and stateful Dynamic Host Configuration Protocol (DHCP). It reviews basic protocols, like Neighbor Discovery Protocol (NDP), and commands, like **ping** and **traceroute**. This section also reviews router configuration for addressing and static routes (leaving OSPFv3 configuration review for Chapter 17, "Implementing OSPF for IPv6").

Unicast IPv6 Addresses and IPv6 Subnetting

IPv6 defines two major types of unicast IPv6 addresses. *Global unicast* addresses work like public IPv4 addresses in that the enterprise obtains a unique prefix with all addresses inside the enterprise beginning with that prefix. With all companies using unique prefixes, all addresses in the IPv6 Internet should be unique.

Unique local unicast addresses work more like private addresses. A company can randomly create a prefix and assign addresses that begin with that prefix. Unique local addresses let companies avoid having to register a prefix while still having a good statistical chance of not using the same address range as other companies.

To create subnets with global unicast addresses, a company starts with the global routing prefix—the prefix assigned to the enterprise—and then breaking the address structure into three parts. In almost all cases, including most cases in this book and the ICND1 book, the combined global routing prefix and subnet part of the address make up the first half (64 bits) of the address structure. The subnet part gives the enterprise network engineer a place to number each subnet with a different value, uniquely identifying each subnet. Then, the remainder of the structure leaving room for a 64-bit interface ID (or host field). Figure 16-1 summarizes these rules.

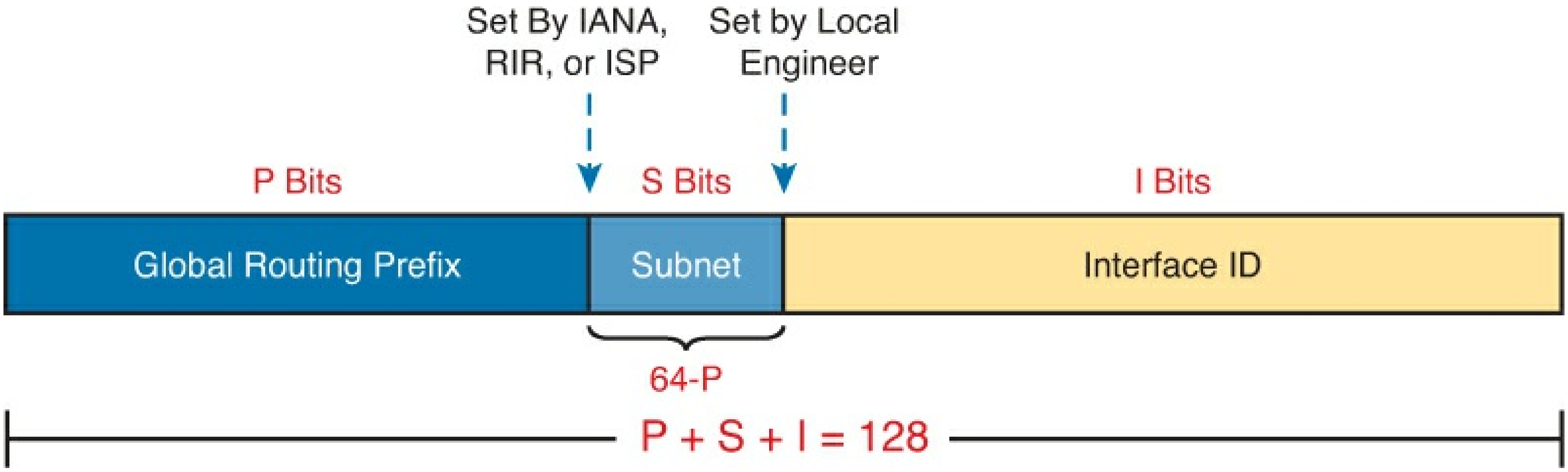


Figure 16-1. Structure of Subnetted IPv6 Global Unicast Addresses

For example, a company might receive a global routing prefix of 2001:DB8:1111::/48. That is, all addresses must begin with those 12 hex digits. The subnet part of the addresses exists in the entire fourth quartet. Those subnet numbers can be (hex) 0000, 0001, 0002, and so on, up through FFFF, for 65,536 possible subnets in this example. As a result, the company might end up with a subnet design as shown in Figure 16-2.

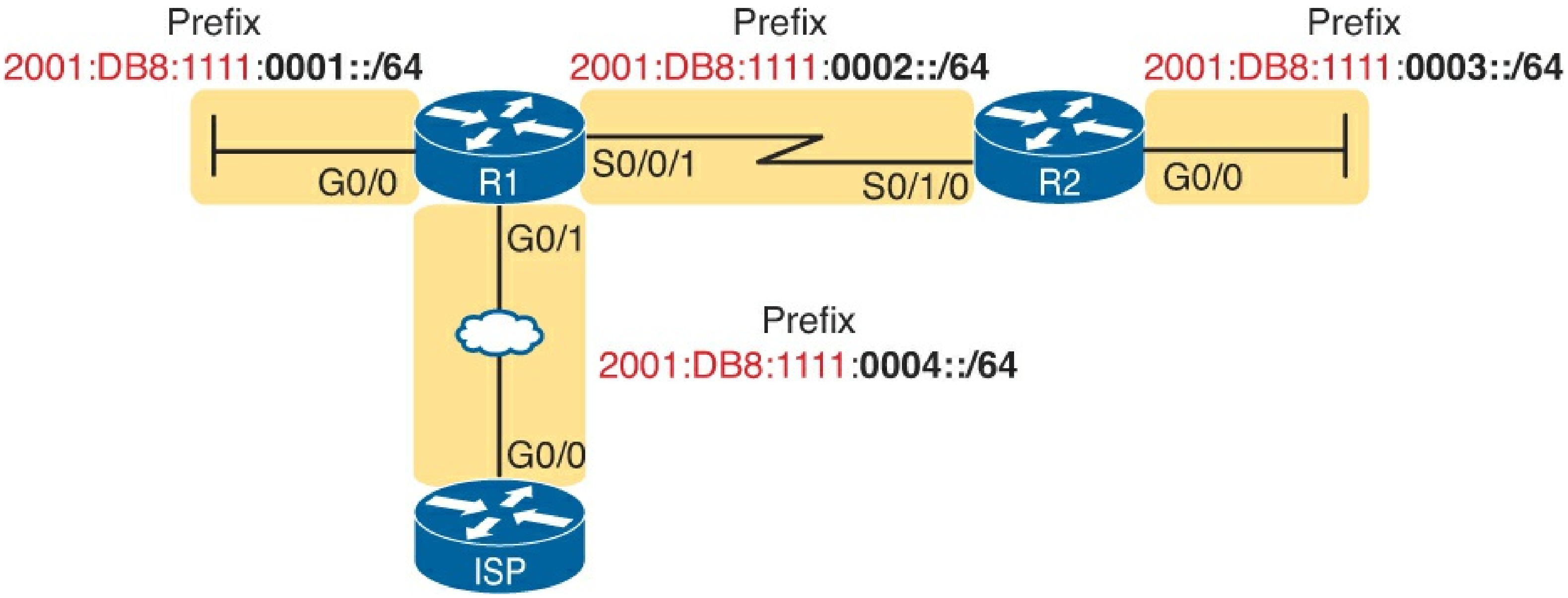


Figure 16-2. Subnet Design with Global Routing Prefix of 2001:0DB8:1111

> **Note**
>
> IPv6 formally uses the term *prefix* rather than *subnet*, but many people use either term when discussing IPv6 addressing.

Although Figure 16-2 is helpful for subnet planning, it does not list the specific IPv6 addresses. Like IPv4, IPv6 follows the same general rules. For example, hosts and routers connected to the same Ethernet VLAN needing to be in the same IPv6 subnet. Figure 16-3 shows an example with the IPv6 addresses in the appropriate subnets to match Figure 16-2.

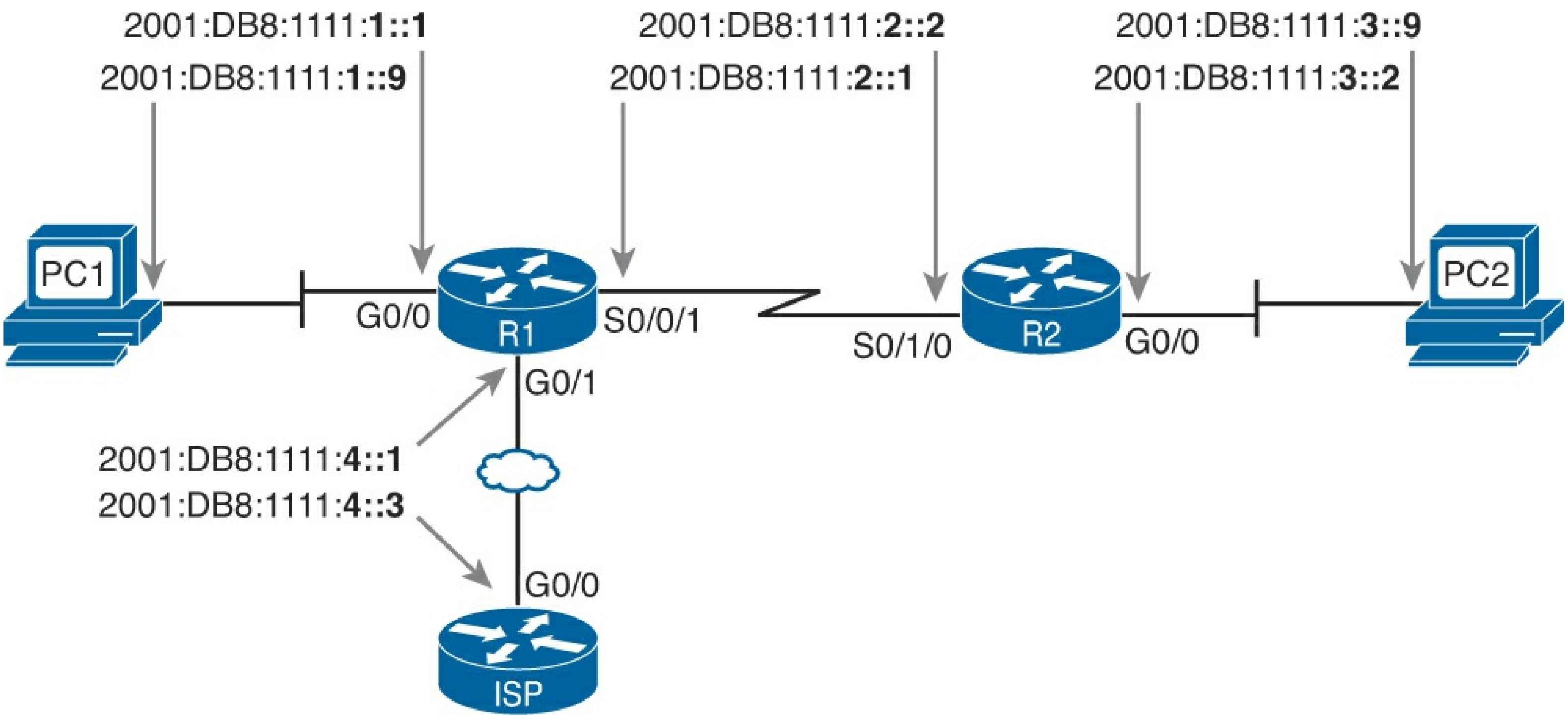


Figure 16-3. Example Static IPv6 Addresses Based on the Subnet Design of Figure 16-2

Hosts can use global unicast and unique local unicast addresses to send and receive IPv6 packets with other hosts, but IPv6 defines a special type of unicast address used for packets that stay on a single link: the *link-local* address. Many protocols need to send IPv6 packets that flow only in the local subnet, with no need for routers to forward the packets to any other subnets. IPv6 uses link-local addresses for these protocols. Note that hosts can create their own link-local address even before the host has a valid global unicast or unique local address.

IPv6 hosts and routers create their own link-local address for each interface using some basic rules. First, all link-local addresses start with the same 16-digit prefix (FE80:0000:0000:0000), as shown on the left side of Figure 16-4. The router or host then forms the final 16 hex digits using EUI-64 rules, as discussed in the upcoming section "Stateless Address Autoconfiguration."

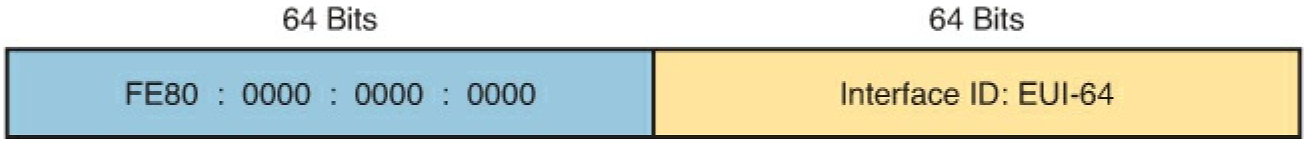


Figure 16-4. Link-local Address Format

Table 16-1 summarizes a few bits of reference information about global unicast and unique local unicasts for reference.

Key Topic

Table 16-1. Summary of IPv6 Unicast Address Types

Type	First Digits	Similar to IPv4 Public or Private?
Global unicast	2 or 3[1]	Public
Unique local unicast	FD	Private
Link-local	FE80	Neither

[1] IANA actually defines the global unicast address range as any address not otherwise reserved for some other purpose. However, actual address assignments normally happen from 2000::/3 because that was the original range used for these addresses. Many IPv6 references simply quote 2000::/3 as the prefix, which means the first hex digit is either a 2 or 3.

Assigning Addresses to Hosts

Once all the addressing details have been discussed, registered, and documented, the addresses must be configured on the various hosts and routers. This next topic examines how to add IPv6 configuration (including addressing) to IPv6 hosts.

From a learning perspective, IPv6 host configuration is a little more complex than IPv4. IPv6 adds another protocol to the mix—Neighbor Discovery Protocol (NDP)—and has two options through which hosts can learn their IPv6 settings. Learning how IPv6 hosts dynamically learn their IPv6 settings just takes a little more effort than with IPv4.

IPv6 hosts have three basic options to set their IPv6 options: static configuration, stateful DHCP, and SLAAC. With static configuration, someone just types the options into the right part of the user interface, so this section does not discuss the static configuration option further. The next two topics look at the two dynamic options.

Stateful DHCPv6

Stateful DHCPv6 follows the same general process as DHCP for IPv4 (DHCPv4):

1. A DHCP server or servers exist somewhere in the internetwork.
2. User hosts use DHCP messages to ask for a lease of an IP address and information about other settings.
3. The server replies, assigning an address to the host and informing the host of the other settings.

The one noticeable difference between DHCPv4 and stateful DHCPv6 is that the stateful DHCPv6 server does not supply the default router information. Instead, a built-in protocol, NDP, lets the host ask the local routers to identify themselves. Otherwise, hosts use the same general process as with DHCPv4. Figure 16-5 shows a comparison of what is learned by a host using DHCPv4 and stateful DHCPv6.

Key Topic

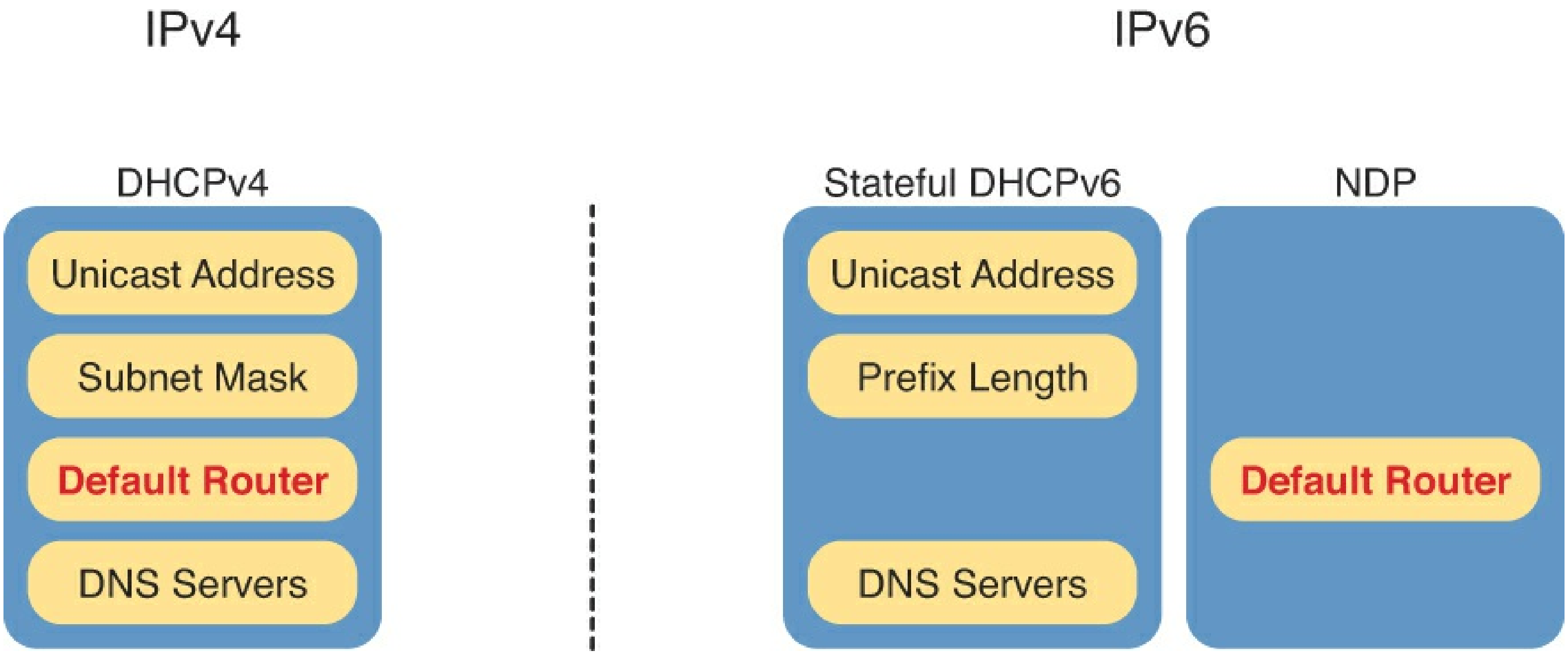

IPv4
IPv6
DHCPv4
Unicast Address
Subnet Mask
Default Router
DNS Servers
Stateful DHCPv6
Unicast Address
Prefix Length
DNS Servers
NDP
Default Router

Figure 16-5. Sources of Specific IPv6 Settings When Using Stateful DHCP

If the stateful DHCPv6 server sits on a different subnet than the host, DHCPv6 relies on the DHCPv6 *relay agent* function, as shown in Figure 16-6. For instance, on the left, host A begins its attempt to learn an address to use by sending a DHCPv6 Solicit message. This message goes to an IPv6 multicast destination address of FF02::1:2, and routers, like R1, would not normally forward a packet sent to this local scope multicast address. However, with the DHCPv6 relay agent configuration added to R1's G0/0 interface, as shown in the figure, R1 forwards host A's DHCPv6 message to the DHCP server.

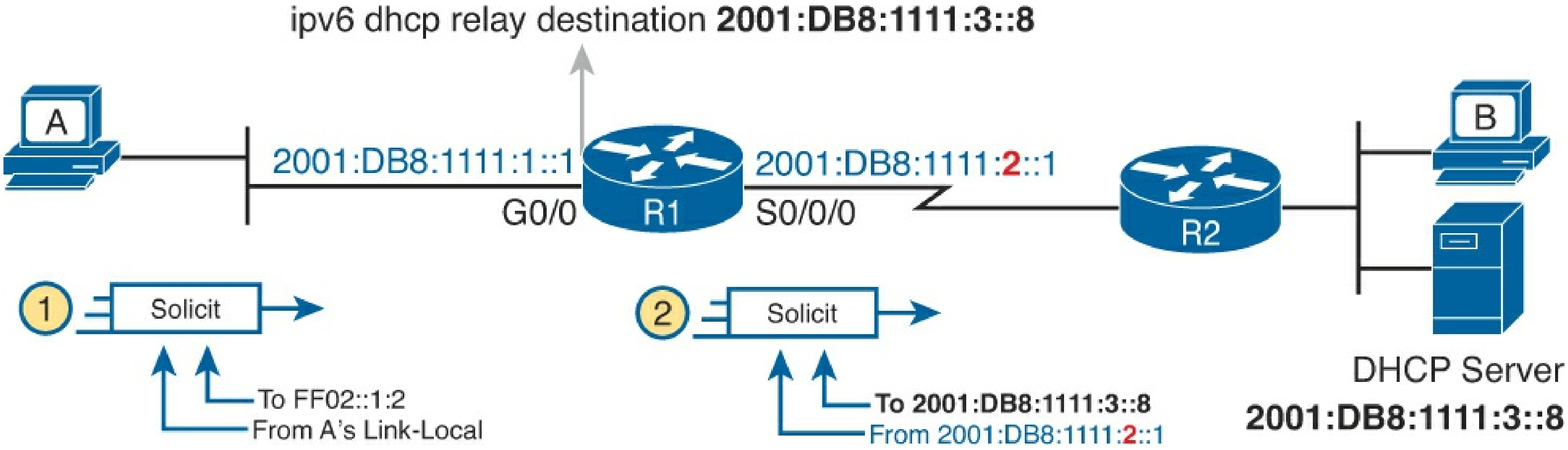

ipv6 dhcp relay destination 2001:DB8:1111:3::8
A
2001:DB8:1111:1::1
G0/0
R1
2001:DB8:1111:2::1
S0/0/0
R2
B
DHCP Server
2001:DB8:1111:3::8
1
Solicit
To FF02::1:2
From A's Link-Local
2
Solicit
To 2001:DB8:1111:3::8
From 2001:DB8:1111:2::1

Figure 16-6. DHCPv6 Relay Agent and DHCP IPv6 Addresses

Stateless Address Autoconfiguration

IPv6's stateless address autoconfiguration (SLAAC) provides an alternative method for dynamic IPv6 address assignment—without needing a stateful server. In other words, SLAAC does not require a server to lease the IPv6 address and record (keep state information) about which host has which IPv6 address, as is the case with the stateful DHCPv6 service.

SLAAC defines an overall process that also uses NDP and DHCPv6 with a stateless service; the server keeps no state information. First, the process takes advantage of NDP, through which the host can learn the following from any router on the link: the IPv6 prefix (subnet ID), the prefix length (mask equivalent), and the default router IPv6 address. The host uses SLAAC rules to build the rest of its address. Finally, the host uses stateless DHCPv6 to learn the DNS server IPv6 addresses. Figure 16-7 summarizes these details for easy study and reference.

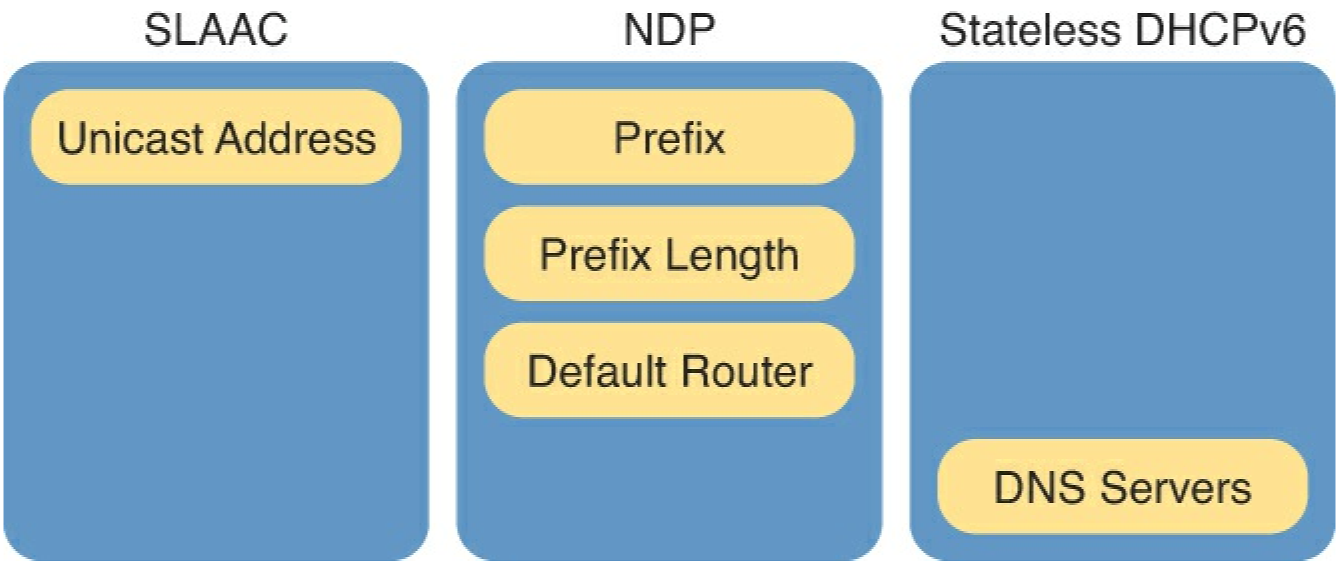

SLAAC
Unicast Address
NDP
Prefix
Prefix Length
Default Router
Stateless DHCPv6
DNS Servers

Figure 16-7. Sources of Specific IPv6 Settings When Using SLAAC

With SLAAC, a host learns values for three settings (prefix length, router address, and DNS servers), but the host builds the value to use as its address. To build the address, a host uses these steps:

1. Learn the IPv6 prefix used on the link, from any router, using NDP Router Solicitation (RS) and Router Advertisement (RA) messages.
2. Choose an interface ID value to follow the just-learned IPv6 prefix, either by randomly choosing a number, or by using the host's MAC address and using EUI-64 rules.

If the host uses the EUI-64 option, the address built by the host can be predicted. The prefix part of the address is the prefix as defined on the local IPv6 router. Then, the host's MAC address feeds into a few EUI-64 rules to change the 48-bit MAC address into a 64-bit interface ID, as follows:

1. Split the 6-byte (12 hex digits) MAC address in two halves (6 hex digits each).
2. Insert FFFE in between the two, making the interface ID now have a total of 16 hex digits (64 bits)
3. Invert the seventh bit of the first byte.

Figure 16-8 shows the major pieces of how the address is formed.

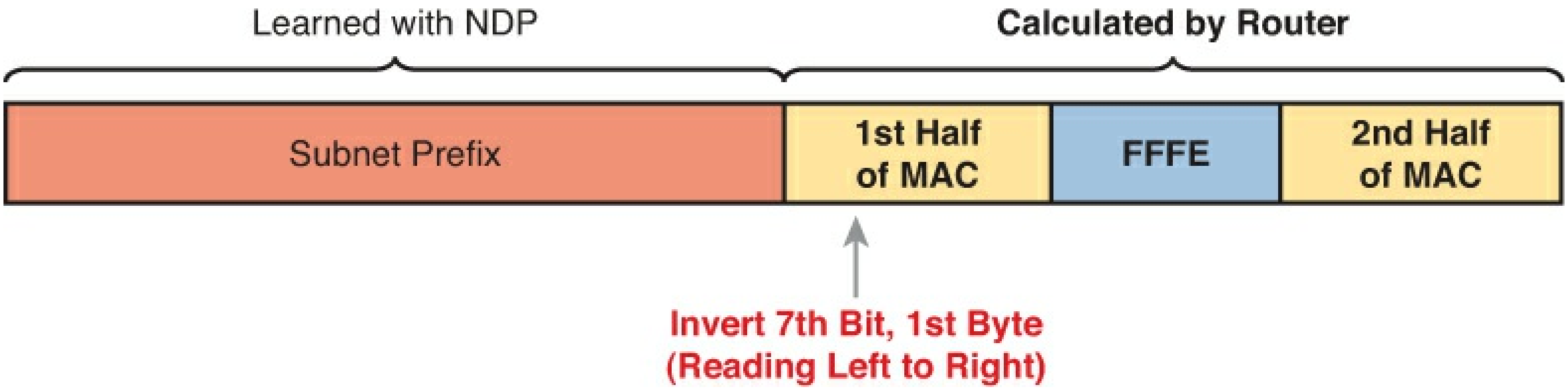

Learned with NDP
Calculated by Router
Subnet Prefix
1st Half of MAC
FFFE
2nd Half of MAC
Invert 7th Bit, 1st Byte (Reading Left to Right)

Figure 16-8. IPv6 Address Format with Interface ID and EUI-64

Router Address and Static Route Configuration

At this point in this section, you have reviewed IPv6 addresses, IPv6 subnetting, and how to assign addresses to hosts. The next topic looks at how to assign addresses to routers, enable IPv6 routing, and configure static IPv6 routes.

Configuring IPv6 Routing and Addresses on Routers

To enable IPv6 on a router, you have two basic tasks:

Key Topic

Step 1. Enable IPv6 routing using the **ipv6 unicast-routing** global command.

Step 2. Enable IPv6 on each desired interface, and set the interface IPv6 address and prefix length, using the **ipv6 address** *address/length* subcommand in interface configuration mode.

In many cases inside enterprises, the IPv6 implementation plan uses a *dual-stack* strategy, at least on the routers and possibly on hosts. That is, the routers still route IPv4 packets and still have IPv4 addresses on their interfaces. The configuration then adds IPv6 routing as a second Layer 3 protocol routed by the routers, leading to the name dual stack.

Example 16-1 shows a configuration example for adding IPv6 configuration to router R1, based on what you saw in Figure 16-3. In that figure, R1 uses three interfaces, with the entire address shown in each case. As a result, Example 16-1 statically configures the entire address. Note also that the prefix length, /64 in this case, sits immediately after the address, without a space. (The IPv4 configuration, not shown, usually already exists with a dual-stack approach.)

Example 16-1. IPv6 Addressing Configuration on Router R1 from Figure 16-3

Click here to view code image

```
ipv6 unicast-routing
!
interface serial0/0/1
ipv6 address 2001:db8:1111:2::1/64
!
interface gigabitethernet0/0
ipv6 address 2001:db8:1111:1::1/64
!
interface gigabitethernet0/1
ipv6 address 2001:db8:1111:4::1/64
```

Alternatively, routers can also use addresses formed using EUI-64 rules. To configure a router for this option, the **ipv6 address** command has two changes. First, the command lists only the prefix, and not the entire address, because the router creates the interface ID part of the address. The command also lists an **eui-64** keyword at the end. For instance, to instead use EUI-64 on R1's G0/0 interface, you use the command **ipv6 address 2001:db8:1111:1::/64 eui-64**.

IPv6 Static Routes on Routers

As for IPv6 routes, most enterprises use a dynamic IPv6 routing protocol, such as Open Shortest Path Version 3 (OSPFv3, Chapter 17) or Enhanced Interior Gateway Routing Protocol Version 6 (EIGRPv6; Chapter 18, "Implementing EIGRP for IPv6"). However, routers also support static routes, of course.

Routers support three basic options for IPv6 static routes about how to tell a router where to send packets next. Figure 16-9 shows all three options, as follows:

1. Direct the packets out an interface on the local router.
2. Direct the packets to the unicast address of a neighboring router.
3. Direct the packets to the link-local address of a neighboring router (requires the outgoing interface, as well).

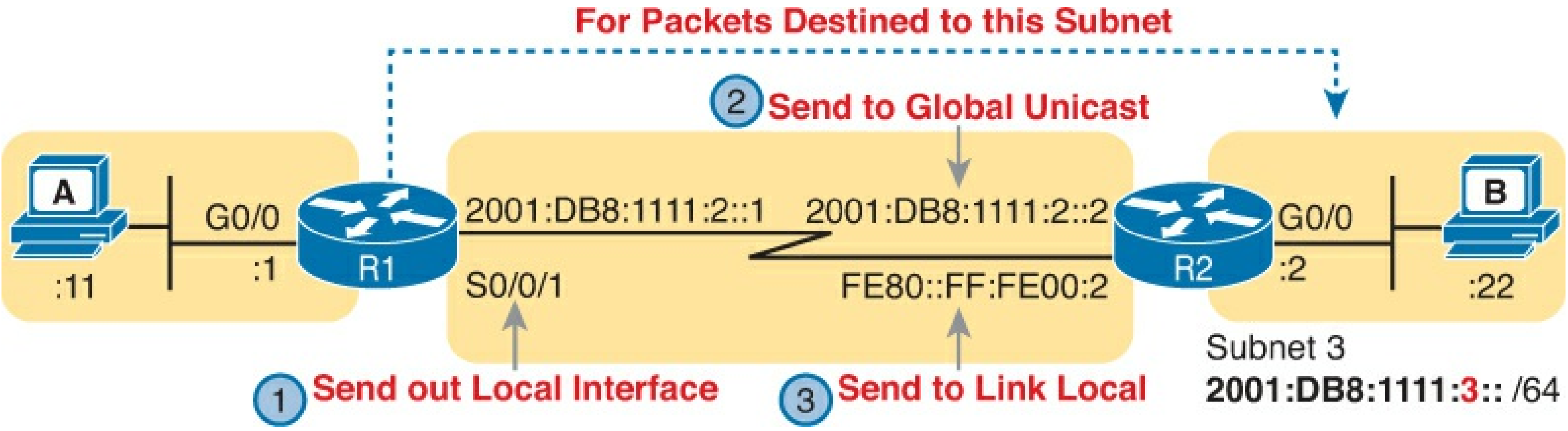

For Packets Destined to this Subnet
2 Send to Global Unicast
A
:11
G0/0
:1
R1
2001:DB8:1111:2::1
2001:DB8:1111:2::2
S0/0/1
FE80::FF:FE00:2
R2
G0/0
:2
B
:22
Subnet 3
2001:DB8:1111:3:: /64
1 Send out Local Interface
3 Send to Link Local

Figure 16-9. Three Options for IPv6 Static Route Configuration

[Example 16-2](#) shows a static route to match the figure in each of the three styles. A single router would not use three static routes for the same destination IPv6 prefix; the example just shows all three as a review of the syntax of each command.

Example 16-2. Static IPv6 Routes: Three Options

[Click here to view code image](#)

```
! The next command uses R1's S0/0/1 as the outgoing interface
ipv6 route 2001:db8:1111:3::/64 S0/0/1

! The next command uses R2's address as the next-hop router unicast address
ipv6 route 2001:db8:1111:3::/64 2001:DB8:1111:2::2

! The next command uses R1's S0/0/1 as the outgoing interface, and
! R2's link-local address as the next-hop router address
ipv6 route 2001:db8:1111:3::/64 S0/0/1 FE80::FF:FE00:2
```

Verifying IPv6 Connectivity

Most troubleshooting tasks, both on the job and for the exam, begin with a partially working network. To find the existing problems, the engineer needs to try various commands to test the network to verify what works properly and what does not. This next topic reviews a few commands useful for verifying IPv6 connectivity both on hosts and on routers.

Verifying Connectivity from IPv6 Hosts

The first item to check with on any IPv6 host should be the four key IPv6 settings on a host, as shown on the left side of [Figure 16-10](#). This verification step should not only look at the host itself but also compare the host's settings to the other devices in the network. For instance, the host's default router (default gateway) setting should match the address configured on a local router.

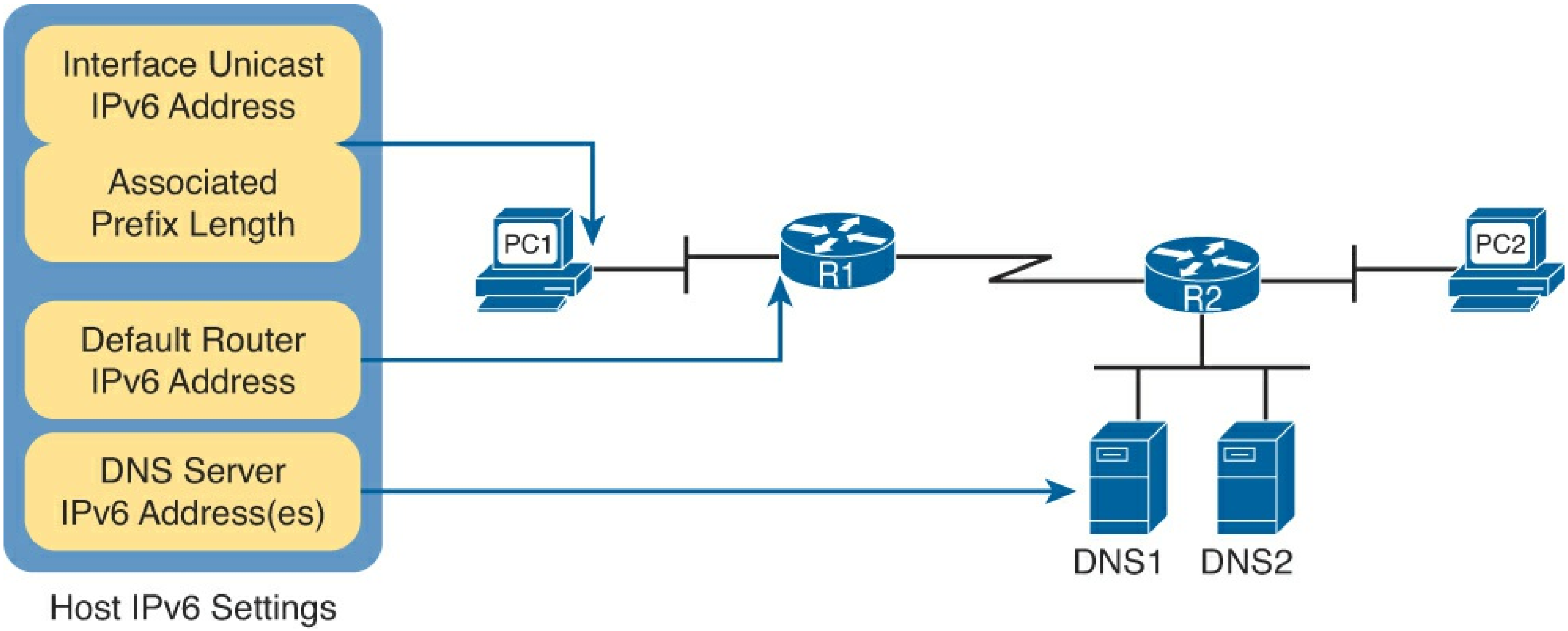

Interface Unicast IPv6 Address
Associated Prefix Length
Default Router IPv6 Address
DNS Server IPv6 Address(es)
Host IPv6 Settings
PC1
R1
R2
PC2
DNS1
DNS2

Figure 16-10. IPv6 Settings Needed on Hosts

Hosts usually support some way to see IPv6 settings from the graphical user interface (GUI) and use commands. For the main four IPv6 settings, the **ipconfig** (Windows operating systems) and **ifconfig** (Linux and Mac OS) usually show some of the settings. Example 16-3 shows an **ifconfig** command from a Linux host with the address and prefix length highlighted for the global unicast and link-local addresses.

Example 16-3. ifconfig **Command Using Linux**

Click here to view code image

```
WOair$ ifconfig en0
eth0: Link encap:Ethernet Hwaddr 02:00:11:11:11:11
inet addr:10.1.1.99 Bcast:10.1.1.255 Mask:255.255.255.0
inet6 addr: fe80::11ff:fe11:1111/64 Scope:Link
inet6 2001:db8:1111:1::11/64 Scope:Global
UP BROADCAST RUNNING MULTICAST MTU:1500 Metric:1
RX packets: 45 errors:0 droppped:0 overruns:0 frame:0
TX packets: 804 errors:0 droppped:0 overruns:0 carrier:0
collisions:0 txqueuelen:1000
RX bytes:5110 (5.1 KB) TX bytes:140120 (140.1 KB)
```

Of course, the best two commands for testing connectivity are the **ping** and **traceroute** commands. Some hosts use the same exact **ping** and **traceroute** commands for both IPv4 and IPv6, whereas others (notably Mac OS and Linux) use a different command for IPv6 (for instance, the **ping6** and **traceroute6** commands).

When using **ping6** for troubleshooting, pinging the nearest IPv6 address and then pinging router addresses further and further away until one of the pings fails can help you isolate the problem. For instance, in Figure 16-11, from PC1 the user could first ping the nearer interface on R1, then the serial interface IPv6 address on R1, then R2s IPv6 address on S0/1/0, and so on.

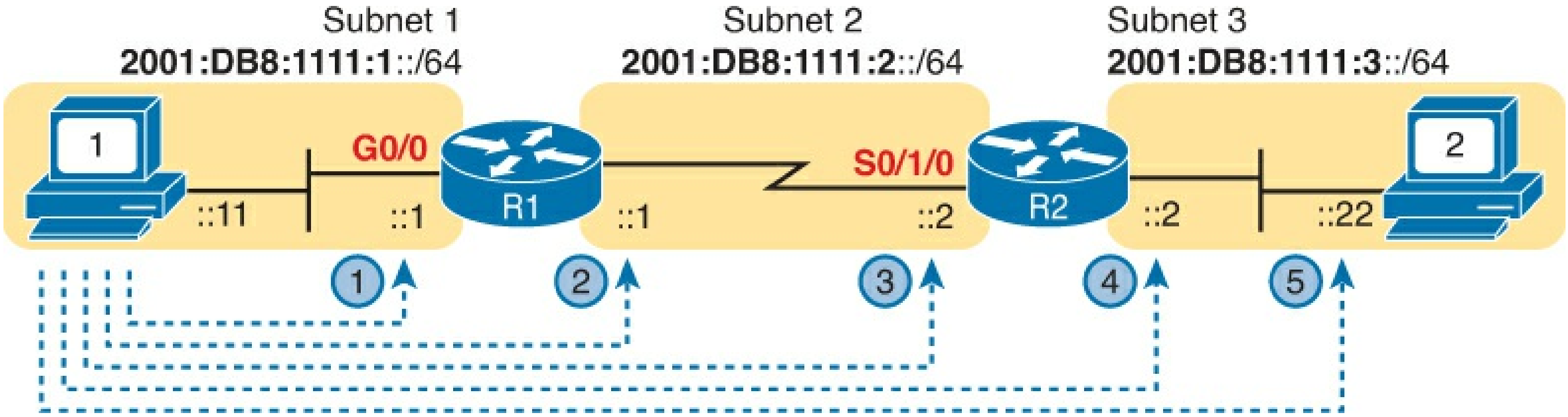


Figure 16-11. Ping Sequence to Isolate an IPv6 Routing Problem

Example 16-4 shows the pings from Steps 1 and 5 from Figure 16-11.

Example 16-4. The ping6 **Command from PC, for R1's Nearer Interface and for PC2**

Click here to view code image

```
Master@PC1:~$ ping6 2001:db8:1111:1::1
PING 2001:db8:1111:1::1 (2001:db8:1111:1::1) 56 data bytes
64 bytes from 2001:db8:1111:1::11: icmp_seq=1 ttl=64 time=1.26 ms
64 bytes from 2001:db8:1111:1::11: icmp_seq=2 ttl=64 time=1.15 ms
^C
--- 2001:db8:1111:1::1 ping statistics ---
2 packets transmitted, 2 received, 0% packet loss, time 1001 ms
rtt min/avg/max/mdev = 1.156/1.210/1.263/0.062 ms

Master@PC1:~$ ping6 2001:db8:1111:3::22
PING 2001:db8:1111:3::22 ( 2001:db8:1111:3::22) 56 data bytes
64 bytes from 2001:db8:1111:3::22: icmp_seq=1 ttl=64 time=2.33 ms
64 bytes from 2001:db8:1111:3::22: icmp_seq=2 ttl=64 time=2.59 ms
64 bytes from 2001:db8:1111:3::22: icmp_seq=3 ttl=64 time=2.03 ms
^C
--- 2001:db8:1111:3::22 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2003 ms
rtt min/avg/max/mdev = 2.039/2.321/2.591/0.225 ms
```

Verifying IPv6 from Routers

Cisco routers support IPv6 with the **ping** and **traceroute** commands. Both commands accept either an IPv4 or an IPv6 address or hostname, and both work as either as a standard or an extended command.

The extended **ping** and **traceroute** commands give you a lot of power to sit at a router CLI and test the reverse route used by the hosts on the connected LANs. Chapter 4, "Troubleshooting IPv4 Routing Part I," in the "Using Extended Ping to Test the Reverse Route" section, discusses the details for IPv4, and the same concepts apply for IPv6. For a brief review here, the extended IPv6 options on the router **ping** and **traceroute** commands let you test routes back to the correct source subnet. For instance, in Figure 16-12, an extended ping from R1 to PC2's IPv6 address tests the forward route to PC2. However, if the extended ping uses R1's G0/0 interface as the source, this command also tests the reverse route back to PC1's IPv6 subnet.

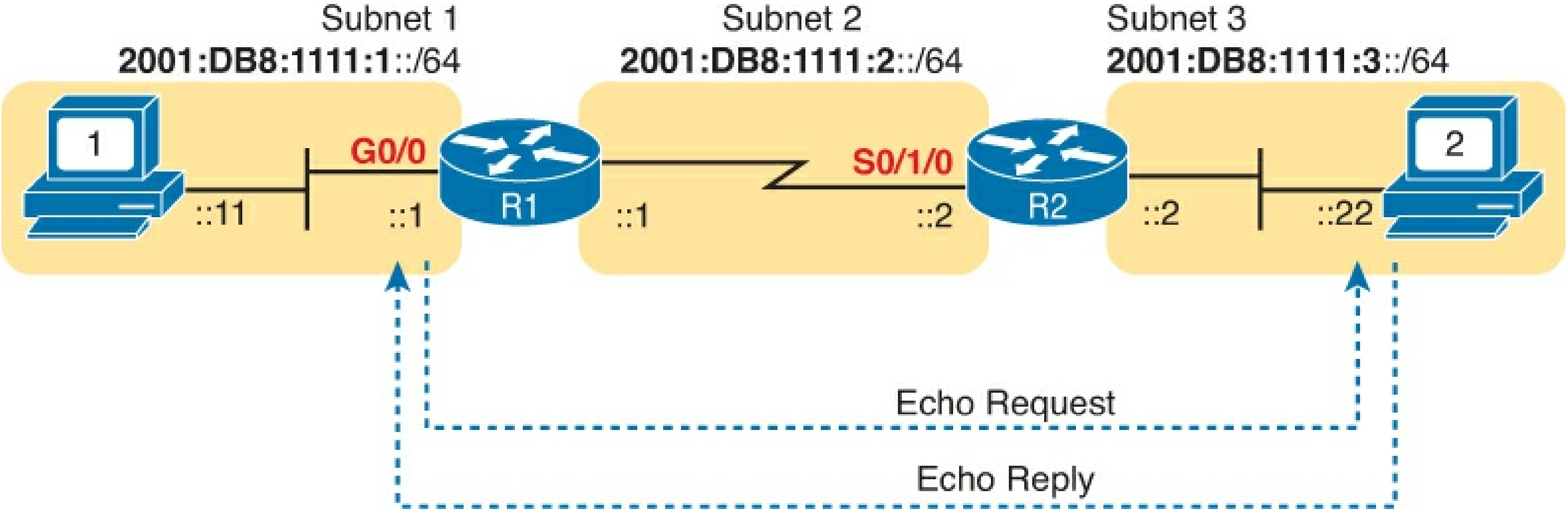


Figure 16-12. Destination and Source Address of Extended Ping in Example 16-5

Example 16-5 shows the extended IPv6 ping from R1 to PC2 using R1's G0/0 interface as the source of the packets. The second command shows a standard IPv6 **traceroute** from R1 to PC2.

Example 16-5. Extended Ping and Standard Traceroute for IPv6 from Router R1

Click here to view code image

```
R1# ping
Protocol [ip]: ipv6
Target IPv6 address: 2001:db8:1111:3::22
Repeat count [5]:
Datagram size [100]:
Timeout in seconds [2]:
Extended commands? [no]: yes
Source address or interface: GigabitEthernet0/0
UDP protocol? [no]:
Verbose? [no]:
Precedence [0]:
DSCP [0]:
Include hop by hop option? [no]:
Include destination option? [no]:
Sweep range of sizes? [no]:
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 2001:DB8:1111:3::22, timeout is 2 seconds:
Packet sent with a source address of 2001:DB8:1111:1::1
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 0/1/4 ms

R1# traceroute 2001:db8:1111:3::22
Type escape sequence to abort.
Tracing the route to 2001:DB8:1111:3::22

1 2001:DB8:1111:2::2 4 msec 0 msec 0 msec
2 2001:DB8:1111:3::22 0 msec 4 msec 0 msec
```

When an IPv6 **ping** or **traceroute** points to some kind of routing problem, several more steps can help isolate the problem to find the root cause. However, this chapter leaves most of the IPv6 routing troubleshooting discussions until Chapters 17 and 18. Both chapters discuss specific reasons why OSPFv3 and EIGRPv6 might fail to put a route into the IPv6 routing table. For now, keep the following two examples in mind when troubleshooting IPv6 problems.

To display the specific IPv6 route a router would use to send packets to a specific destination address, just use the **show ipv6 route** *address* command. The command lists several lines that detail the route the router will use. If the router has no matching route, the router lists a message of "Route not found." Example 16-6 shows an example in which the matched route is a static route that forwards packets out interface S0/0/1. It also shows an example where no route was found.

Example 16-6. Displaying the Router R1 Uses to Forward to 2001:DB8:1111:3::22

Click here to view code image

```
R1# show ipv6 route 2001:db8:1111:3::22
Routing entry for 2001:DB8:1111:3::/64
Known via "static", distance 1, metric 0
Route count is 1/1, share count 0
Routing paths:
directly connected via Serial0/0/1
Last updated 00:01:29 ago

R1# show ipv6 route 2001:1:1:1::1
% Route not found
```

In addition, the **show ipv6 neighbors** command lists the IPv6 replacement for the IPv4 Address Resolution Protocol (ARP) table. If a ping fails, and an expected entry is missing from this table, that fact might point to an issue that is preventing NDP from discovering the neighbor's MAC address. Example 16-7 shows this command on router R2 from Figure 16-12, listing PC2's IPv6 and matching MAC address.

Example 16-7. The show ipv6 neighbors **Command on Router R2**

Click here to view code image

```
R2# show ipv6 neighbors
IPv6 Address Age Link-layer Addr State Interface
FE80::11FF:FE11:1111 0 0200.1111.1111 STALE Gi0/0
FE80::22FF:FE22:2222 1 0200.2222.2222 STALE Gi0/0
2001:DB8:1111:3::22 0 0200.2222.2222 REACH Gi0/0
FE80::D68C:B5FF:FE7D:8200 1 d48c.b57d.8200 DELAY Gi0/0
2001:DB8:1111:3::33 0 0200.1111.1111 REACH Gi0/0
2001:DB8:1111:3::3 0 d48c.b57d.8200 REACH Gi0/0
```

Troubleshooting IPv6

Imagine that you work with a medium-sized enterprise network that uses IPv6. It works well, you go home on time every day, and life is good. Then one day you go to work and get a text about a problem with the network. So, what do you do? You try some commands, try to isolate the problem, and eventually, find the root cause of the problem. For example, maybe a user had a problem and a co-worker "helped" and configured that user's PC with static IPv6 settings and made a typo in the default router IPv6 address.

The rest of this chapter presents seven different IPv6 troubleshooting scenarios, as if an engineer had just started working a problem. Each problem assumes that the engineer has determined that the problem exists in a particular part of the network or for a particular set of reasons.

Each scenario then gives us a place to talk about potential root causes that happen to show up with a particular set of symptoms and to review the whys and wherefores behind those symptoms.

Before getting into the specific scenarios, the following three lists break down some important facts that should be true about a working IPv6 network. Many of the root causes of problems in this section of the chapter happen because one of these rules was broken.

Key Topic

Host-Focused Issues

1. Hosts should be in the same IPv6 subnet as their default router.
2. Hosts should use the same prefix length as their default router.
3. Hosts should have a default router setting that points to a real router's address.
4. Hosts should have correct Domain Name Service (DNS) server addresses.

Router-Focused Issues

1. Router interfaces in use should be in an up/up state.
2. Two routers that connect to the same data link should have addresses in the same IPv6 subnet.
3. Routers should have IPv6 routes to all IPv6 subnets as per the IPv6 subnet design.

Filtering Issues

1. Watch for MAC address filtering on the LAN switches.
2. Watch for missing VLANs in switches.
3. Watch for IPv6 access control lists (ACL) in routers.

Before diving into the scenarios, if you stop and think about these lists, all the items apply in concept to both IPv4 and IPv6. So, the IPv6 troubleshooting process and concepts should mirror IPv4 to some degree. Of course, the specifics do differ, and these scenarios bring out those differences as well.

Now on to a variety of IPv6 problem symptoms!

Pings from the Host Work Only in Some Cases

Our network engineer has responded to a new problem request by calling the user. The engineer asks the user to do some IPv6 **ping** commands from the user's PC. Some pings actually work, but some do not. What should he try next?

Frankly, at this point, if you ask that same question to ten experienced network engineers, you would probably get five or six different suggested next steps. But one highly productive next step when a host gets some pings to work and some do not work is to check the host's IPv6 settings.

The static IPv6 settings on a host can be one of the most common places to find a mistake, and some of those mistakes results in the "some pings work, some do not" symptom. First, the numbers are long and easy to mis-type. Second, you have to make sure that you understand what has to match on the router and DNS server, as well. Finally, for exams, the people writing the exam questions have a lot of small settings to change to make new questions, so it is easy to create a new question by just editing a drawing and changing one number. So, just as with IPv4, you need to be ready to check IPv6 host settings.

Figure 16-13 collects all the pieces that should match. The concepts mirror the same concepts in IPv4.

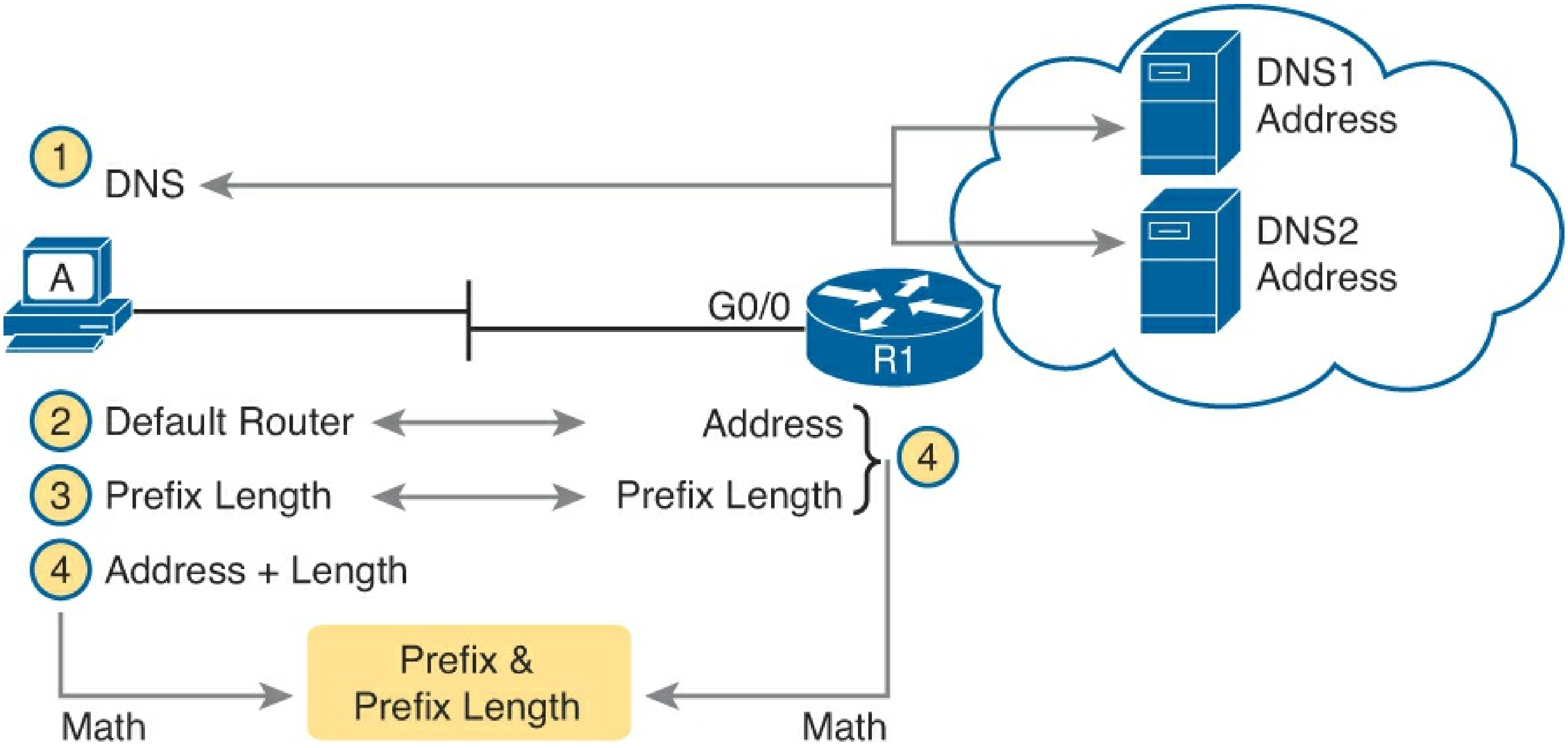


Figure 16-13. Host IPv6 Settings Compared to What the Settings Should Match

Next, think about the symptoms of the ping tests, assuming one, but only one, of these settings is wrong. (If more than one setting is wrong, it makes the symptoms harder to describe here.) Here is a walkthrough of the settings numbered in the figure:

1. With the DNS setting as the one incorrect setting, pings that refer to a hostname will fail, but pings to an IPv6 address should work (again assuming no other problems exist).
2. With the default router setting as the only incorrect setting, pings based on IPv6 address in the local LAN should work. However, pings to addresses outside the subnet (that therefore use the default router) fail. Also, because name resolution would fail, all pings that use names would also fail.
3. If the prefix lengths do not match, the host and router disagree about the subnet on the LAN (see the next step).
4. If the host and router disagree about what IPv6 subnet exists on the VLAN, the routers might not be able to route packets back to the host. As a result, the same ping symptoms as Step 2 occur.

From an exam-taking perspective, you want to work through these symptoms as fast as possible. So, if the question gives you the host settings, check them against the router interface address and prefix length and the DNS server address info, because doing so should take only a little time.

From the perspective of troubleshooting for your job, these symptoms reduce to basically two sets of symptoms:

- Pings that use names happen to fail
- Pings that require off-subnet packets happen to fail

For these two sets of symptoms, the first case points to some DNS problem, and the second points to either a default router issue or a mismatched subnet issue.

Pings Fail from a Host to Its Default Router

Now, on to a second scenario. The engineer has checked out a problem with commands on the host and on that host's default router. All the IPv6 settings on the host and the default router look good. However, when the user at the host pings faraway servers, the pings, both by name and by IPv6 address, fail.

As a next step, the network engineer tries to narrow down the scope a bit with some local pings. The engineer asks the user to just ping from the host to the default router IPv6 address. This ping fails, as well. The engineer tries the reverse—a ping from the default router to the host—and it fails as well.

To summarize, the host cannot ping its default router or vice versa. With these initial problem symptoms, the question is this: What possible root causes would result in these symptoms? For instance, in Figure 16-14, what prevents host B from pinging router R3, particular after you rule out the host and router IPv6 settings?

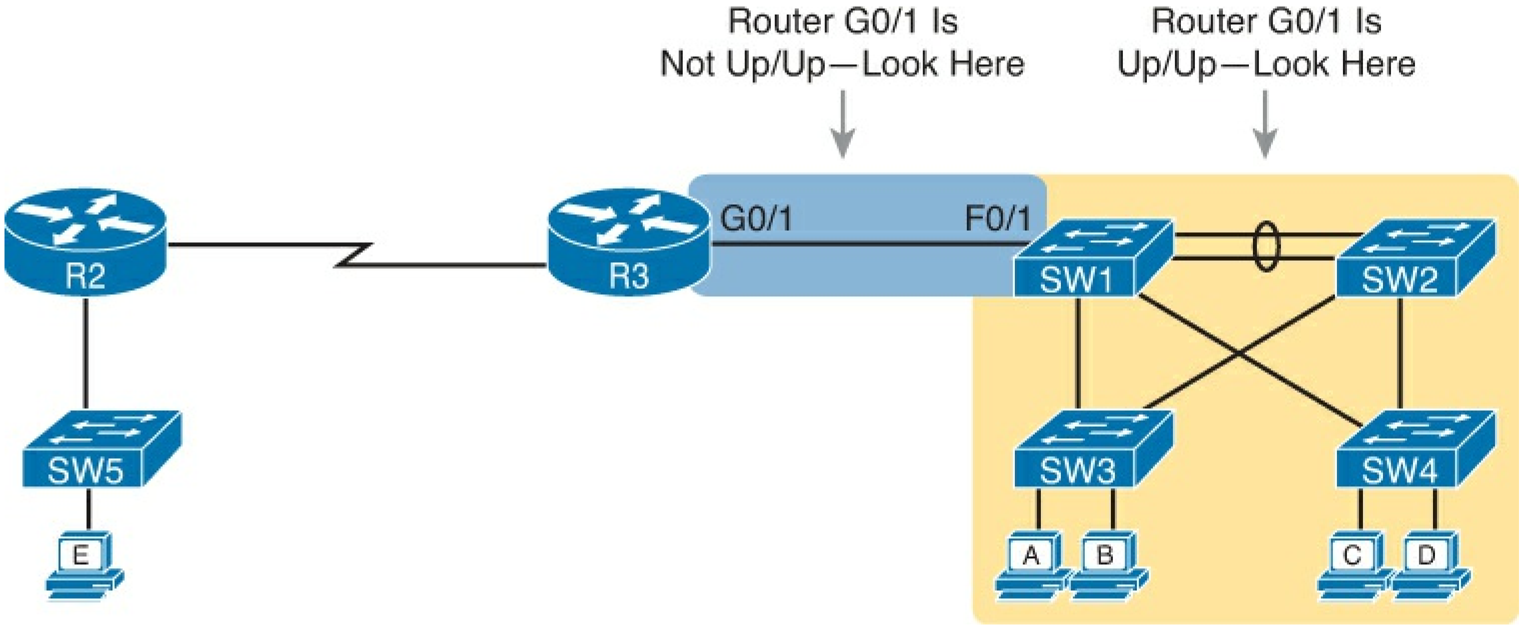

Router G0/1 Is Not Up/Up—Look Here
Router G0/1 Is Up/Up—Look Here
G0/1
F0/1
R2
R3
SW1
SW2
SW3
SW4
SW5
E
A
B
C
D

Figure 16-14. Where to Look for Problems Based on Router LAN Interface Status

To find the problem, the engineer needs to start thinking outside the IPv6 world and start thinking about the LAN between the host and the router. In particular, the probable root causes can be broken down into these categories:

Key Topic

1. The router or host LAN interface is administratively disabled.
2. The LAN has some problem that prevents the flow of Ethernet frames.
3. The LAN has filtering (for example, port security) that filters the Ethernet frames.

First, the router and host can be told to stop using an interface. Routers, of course, use the **shutdown** interface subcommand; if R3's G0/1 were shut down at this point, the engineer would have seen the **ping** results described for this scenario. Hosts also have ways to disable and enable their interfaces, which again would result in this same set of ping symptoms. The solution? Use a **no shutdown** command on the router or enable the interface on the host.

As for in the second problem in the list, Part I of this book has already discussed LAN problems at length. However, as a troubleshooting tip, note that if R3's G0/1 interface is in a down/down state, a LAN problem would likely exist on the Ethernet link directly connected to R3's G0/1 interface. However, if R3's G0/1 is in an up/up state, any LAN problem probably exists elsewhere in the LAN itself. If the ping still does not work, review the information covered in Chapter 3, "Troubleshooting LAN Switching."

As for the third problem in the list, it could be that some filtering mechanism, like port security, is purposefully filter the frames sent by the host (B) or the router (R3 G0/1). Also, router R3 could have an inbound IPv6 ACL on its G0/1 interface, one that unfortunately filtered inbound ICMPv6 packets, which would discard the incoming packets generated by the **ping** commands.

Problems Using Any Function That Requires DNS

Moving on to the third unique troubleshooting scenario, our engineer is troubleshooting a problem for host C. A ping from host C to a Server1 by hostname fails, but a ping to Server1's IPv6 address succeeds. The engineer tries another similar testing, pinging another server (Server2), with the same results: The ping to the hostname fails, and the ping to the IPv6 address works.

These symptoms pretty clearly point to "some kind of name resolution problem." However, that does not define the specific root cause that the engineer can go fix to get the user working again. In this case, the root causes could fall into these categories:

1. An incorrect host DNS server setting, as statically defined on the host
2. An incorrect host DNS server setting, as learned with (stateless or stateful) DHCPv6
3. An IPv6 connectivity problem between the user's host and the DNS server

As for the first root cause listed here, if the host's DNS server setting is wrong, the host sends the DNS requests to the wrong destination address. As a result, the host gets no DNS response and does not learn the IPv6 address of the destination host. The root cause? Someone typed the wrong information into the host IPv6 configuration settings.

The second root cause in the list is similar to the first, but different enough to be worth having a second category. The user's computer has an incorrect DNS server setting, but that IPv6 learned the setting using DHCPv6. Basically, you have the same problem symptoms but a different root cause. As a reminder, both with stateful DHCPv6 and with SLAAC, the host learns the DNS addresses using DHCPv6.

The third root cause requires a little more discussion and an example. The example shows host C in Figure 16-15, with the two-step process that happens the first time the host tests Server1 with a **ping Server1** command. First, IPv6 packets must flow from C to the DNS server and back for the purpose of name resolution. At Step 2 in the figure, IPv6 packets can flow to Server1's IPv6 address.

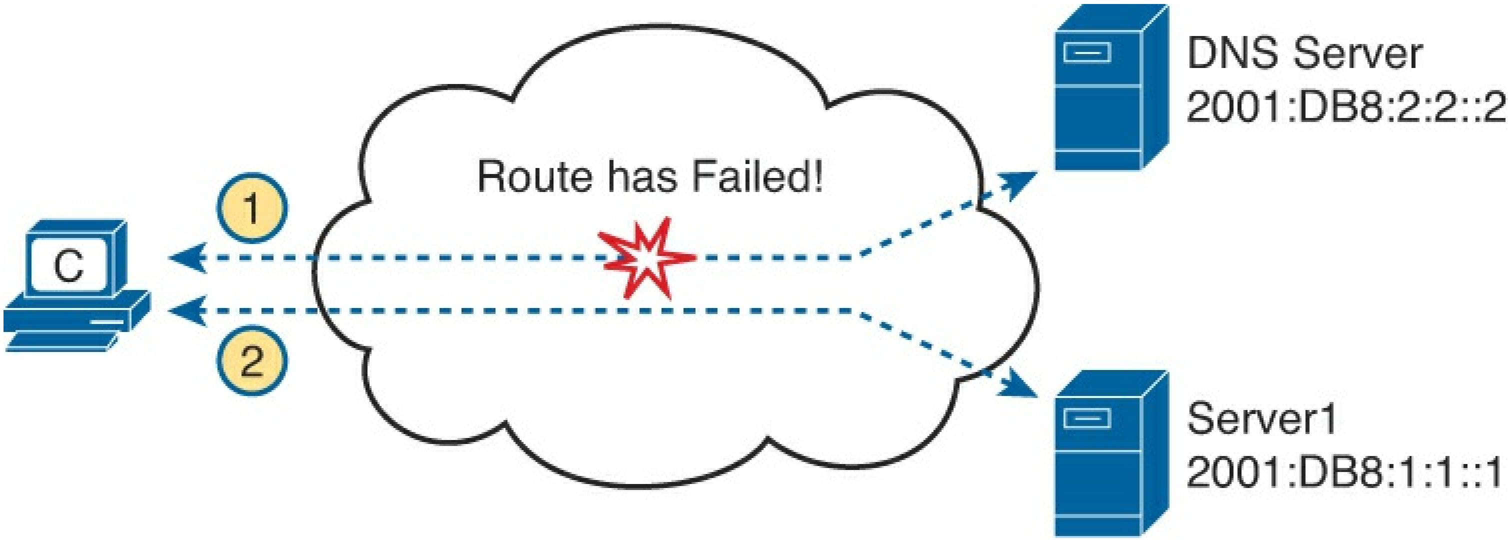


Figure 16-15. DNS Name Resolution Before Forwarding the Packet to the Server

Depending on the topology in the cloud, a connectivity problem may exist between host C and the DNS server, whereas no such problem exists between C and Server1. So, when the problem symptoms point to a "name resolution is not working" set of symptoms, but the host appears to point to the right DNS server addresses, start looking at basic IPv6 connectivity from the host to the DNS server.

Host Is Missing IPv6 Settings: Stateful DHCP Issues

Turning the page to yet another new scenario, our network engineer is now working a problem for a user of a host D. The engineer has called and asked the user to issue a few commands, and the engineer has determined that the host is trying to dynamically learn its IPv6 settings and that the host does not have an IPv6 unicast address yet.

For the sake of discussion, assume that this network uses a strategy of assigning IPv6 addresses using DHCPv6 to assign

IPv6 addresses. The engineer knows this strategy, so the engineer is already wondering why the process failed. This scenario walks through some potential root causes of straightforward mistakes.

> **Note**
>
> This book leaves out some details of what happens in the process of how a host is told whether to use SLAAC or stateful DHCPv6. To keep the discussion clean and in scope of the topics in this book, assume that for this discussion only stateful DHCP is in use.

Stateful DHCP troubleshooting follows the same basic logic as for IPv4 DHCP, as discussed in Chapter 5, "Troubleshooting IPv4 Routing Part II," in the "DHCP Relay Issues" section. So, repeating rules like those introduced in Chapter 5, the following must be true for an IPv6 host to successfully use either stateful or stateless DHCPv6 to learn information from a DHCPv6 server:

Key Topic

1. The server must be in the same subnet as the client.

   Or

2. The server may be in a different subnet, with
   - **A.** The router that sits on the same subnet as the client host correctly implementing DHCP relay
   - **B.** IPv6 connectivity working between that local router (the router near the client host) and the DHCPv6 server

The two most likely root causes of a host failing to dynamically learn its IPv6 settings with stateful DHCPv6 are root causes 2A and 2B. For 2A, the solution requires a configuration command on the correct interface on each LAN that is remote from the DHCPv6 server. For instance, in Figure 16-16, host D sits on a LAN subnet on the left, with R1's G0/0 interface connected to the same subnet. R1 should have the command listed at the bottom of the figure to enable the IPv6 DHCP relay function pointing to the DHCPv6 server on the right.

Key Topic

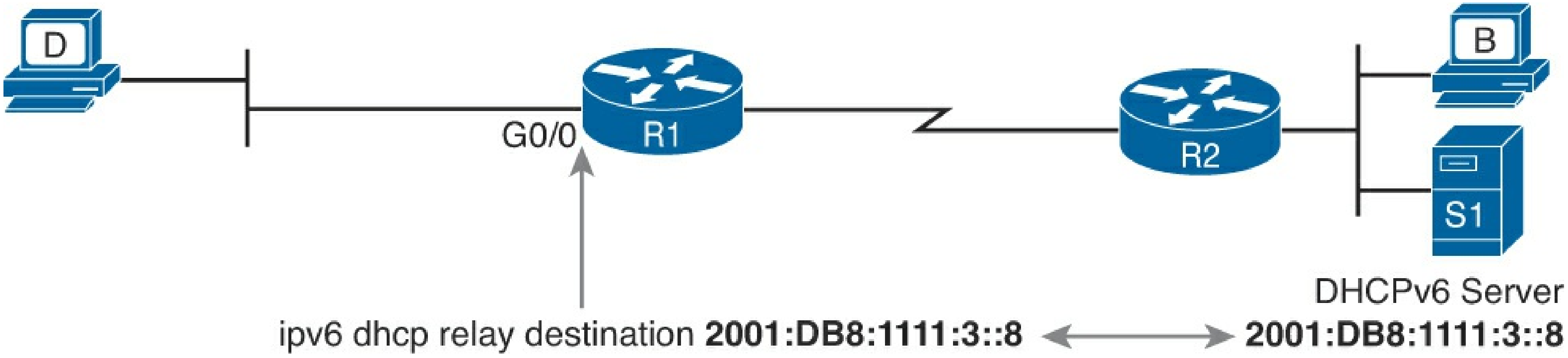


Figure 16-16. IPv6 DHCP Relay

If R1 is missing the **ipv6 dhcp relay** command or points to the wrong IPv6 address, host D's attempt to use DHCPv6 will fail.

The item listed as 2B is not actually a root cause. Instead, it is just another problem symptom that needs further investigation. Connectivity must exist between R1 and the DHCPv6 server, and back to the address R1 uses to source the DHCPv6 message. (R1 sources the DHCPv6 request from the outgoing interface of the sent message, not necessarily the same interface where the **ipv6 dhcp relay** command is configured; in this case, R1 would use its serial interface IPv6 address.) A good test of this problem is to ping the DHCPv6 server's IPv6 address from R1.

Host Is Missing IPv6 Settings: SLAAC Issues

For the fifth troubleshooting scenario, take the previous scenario but assume the enterprise uses SLAAC rather than stateful DHCPv6 for IPv6 address assignment. To review, the engineer has discovered that host D has not learned its IPv6 address. So, what could cause SLAAC to fail? This next topic explores the potential root causes.

To understand some of the root causes for such a problem, first review the three steps a host takes when using SLAAC to learn and build its IPv6 settings:

1. Use NDP to learn the prefix, prefix length, and default router address from a router on the same subnet.
2. Use SLAAC rules, locally on the host (no network messages required), to build the host's own IPv6 address.
3. Use stateless DHCPv6 to learn the addresses of the DNS servers from a DHCPv6 server.

The first of these steps uses the NDP Router Solicitation (RS) message, with the router sending back an NDP Router Advertisement (RA) message, as shown in Figure 16-17. The RS message, sent to the all IPv6 routers multicast address FF02::2, should go to all IPv6 routers on the same VLAN as host D in the figure. In this case, R1 replies, listing R1's IPv6 address (to be used as D's default router) and the prefix/length host D should use.

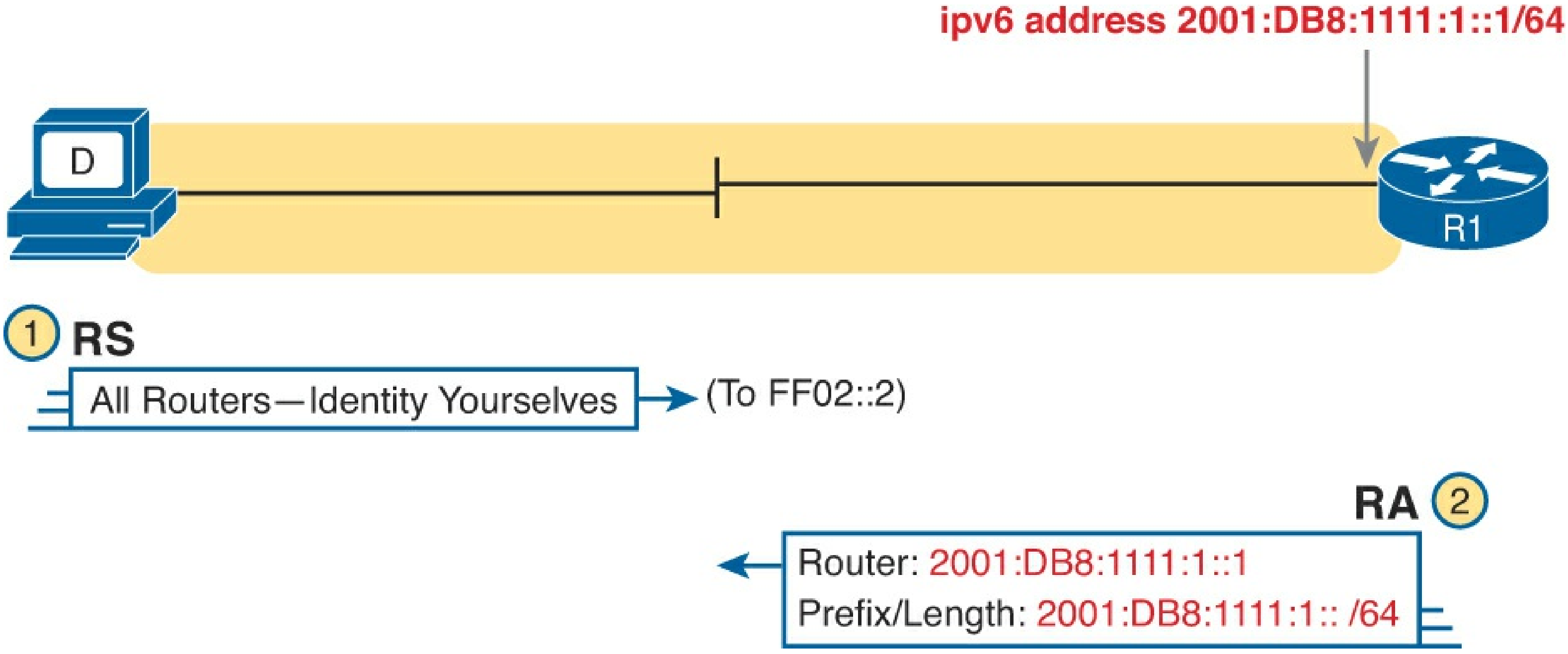

ipv6 address 2001:DB8:1111:1::1/64
D
R1
1 RS
All Routers—Identity Yourselves
(To FF02::2)
RA 2
Router: 2001:DB8:1111:1::1
Prefix/Length: 2001:DB8:1111:1:: /64

Figure 16-17. NDP RS and RA Process

Hosts that use SLAAC rely on the information in the RA message. So, when a host fails to learn and build these three settings when using SLAAC, including the IPv6 address, the next question really should be this: What could cause the NDP RS/RA process to fail? The following list details these potential root causes:

1. No LAN connectivity between the host and any router in the subnet.
2. The router is missing an **ipv6 address** interface subcommand.
3. The router is missing an **ipv6 unicast-routing** global configuration command.

Of these reasons, the first is somewhat obvious. If the LAN cannot forward Ethernet frames from the host to the router, or vice versa, the NDP RS and RA messages cannot be delivered.

As for the second reason, to respond to an RS message, a router must have an **ipv6 address** command. This command enables IPv6 on the interface, but it also defines the information that the router will list in the RA message. For instance, in Figure 16-17, R1 has been configured with the **ipv6 address 2001:db8:1111:1::1/64** command. This command directly lists two of the pieces of information R1 supplies in the RA message, and R1 uses the address and prefix length to calculate the IPv6 prefix as well.

The third root cause in the list may be the most surprising: The router must enable IPv6 routing with the **ipv6 unicast-routing** global command. Why? Without this command, Cisco routers do not try to route IPv6 packets. If omitted, the router does not consider itself an IPv6 router and does not reply to the NDP RS message with an RA.

Traceroute Shows Some Hops, But Fails

This chapter's sixth different troubleshooting scenario now moves away from the host and toward the routers, leading toward IPv6 routing issues.

In this case, the engineer hears that a host cannot connect to a server. Clearly, a ping from the host to the server fails, so the engineer does several of the steps discussed already in this chapter:

- The host IPv6 settings look good.
- The host IPv6 settings match the default router and DNS server as they should.
- The host can ping its default router.

To continue troubleshooting, the engineer next calls the user and asks him to try a **traceroute** command with a destination of the server's IPv6 address. The **traceroute** shows a couple of routers in the output, but then the command never completes until interrupted by the user. What could the root causes be? Usually, but not always, these symptoms point to some kind of an IPv6 routing problem. For the next page or two, this discussion examines some potential root causes for these routing problems.

Routing problems happen for many reasons. Some routing problems happen because routes are missing from a router (perhaps because of many specific root causes). Some routing problems happen because a router has an incorrect route. The following list gives just some of the reasons why a router might be missing a needed route or might have an incorrect route:

- Links between routers are down.
- Routing protocol neighbor problems exist.
- Routing protocol route filtering prevents the route from being added to the IPv6 routing table.
- Incorrect static routes send packets to the wrong next router.
- Poor subnet design duplicates subnets in different locations in the network, falsely advertising a subnet.

For example, take a look at Figure 16-18. Host A fails when attempting to ping host C, which sits in subnet 33 (2001:DB8:1:33::/64). A traceroute of host C from host A lists R1's and R2's IPv6 addresses, but then it never finishes.

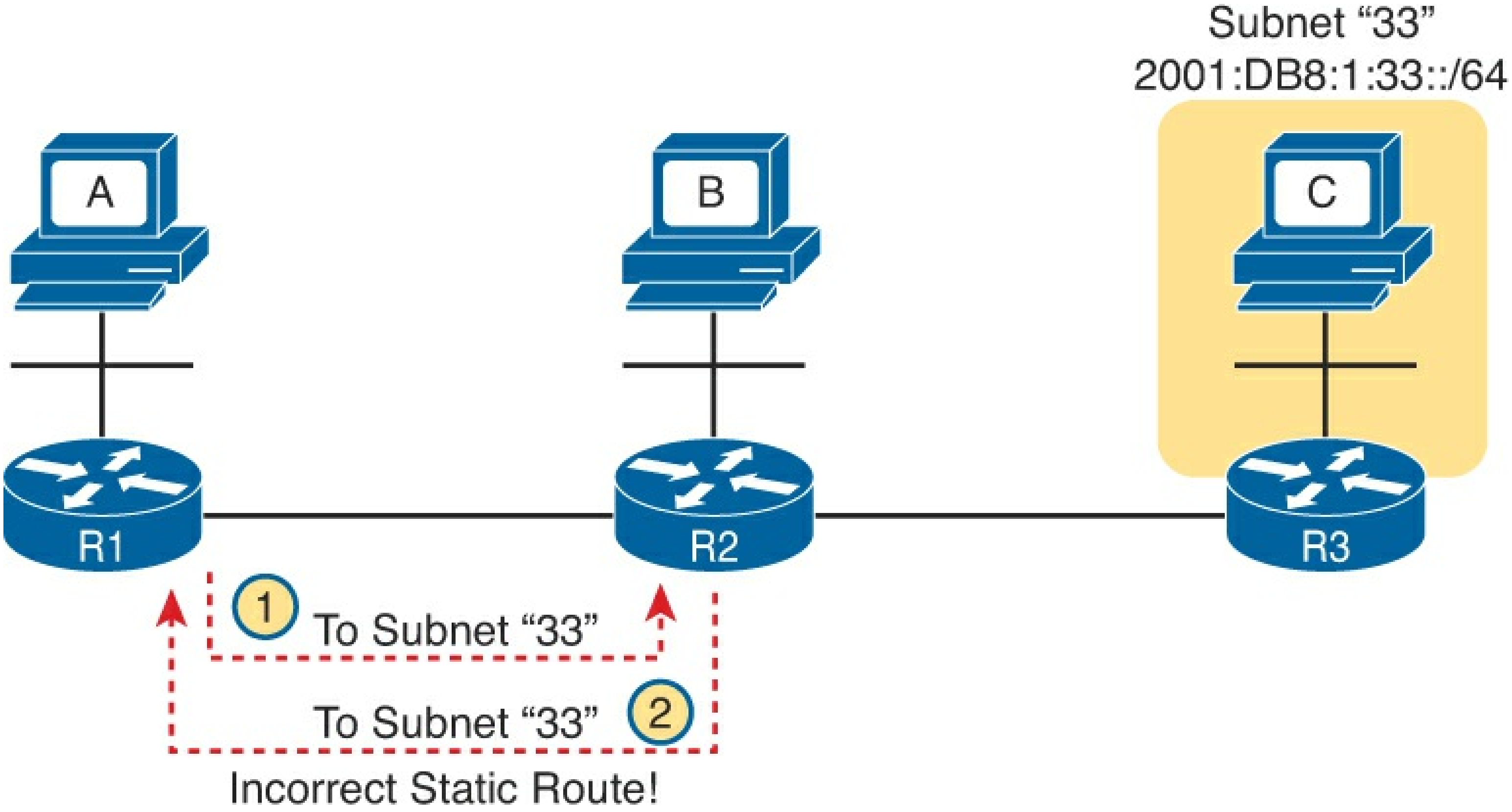


Figure 16-18. Incorrect Static Route Creates Routing Loop

As you can see from the notes in the figure, the routing problem exists because of an incorrect static route on R2. Host A can forward IPv6 packets to R1, its default router. R1 can correctly forward packets sent to host C to router R2. However, R2 has an incorrect static route for subnet 33 pointing back to R1.

As for other root causes of routing problems, take the list and look for those issues as well. Check the interfaces on routers that should be up to make sure the interfaces still work. Do troubleshooting for your routing protocol. (Chapters 17 and 18 discuss how to troubleshoot OSPFv3 and EIGRPv6, respectively.) And even look for the possibility that someone misconfigured a router interface, so that the routing protocols advertise about the same subnet number as existing in two places, which breaks design rules on paper and confuses the routing of packets to hosts in that IPv6 subnet.

Routing Looks Good, But Traceroute Still Fails

To finish this set of scenarios, this last scenario focuses on one particular root cause: IPv6 access control lists (ACL).

You have already learned how **ping** and **traceroute** commands can imply that a routing problem may exist. When ping and traceroute show that the host can forward a packet at least as far as the default router but not all the way to the destination, the problem probably sits in one of these two categories:

- A routing problem exists.
- Routing works, but some filter, like an IPv6 ACL, is discarding the packets.

Although neither this book nor the ICND1 book discusses IPv6 ACLs, the ICND1 book discussed IPv4 ACLs quite a bit. IPv6 ACLs work very much the same, but of course, they filter IPv6 packets rather than IPv4 packets. IPv6 ACL configuration defines a list of statements, with each statement matching source and destination IPv6 address ranges, port numbers, and so on. You can enable the ACL to filter IPv6 packets as they flow in or out of an interface.

For instance, Figure 16-19 shows a single line IPv6 ACL (with correct syntax). IPv6 ACLs define the source and destination address ranges as an address/prefix pair, just like in the **ipv6 address** interface subcommand. To filter Telnet traffic going from subnet 1 to subnet 3 in this network, you could add the ACL in one of the four locations noted with the arrowed lines in the figure. (Note that the ACL would also need some other statements to permit other traffic.)

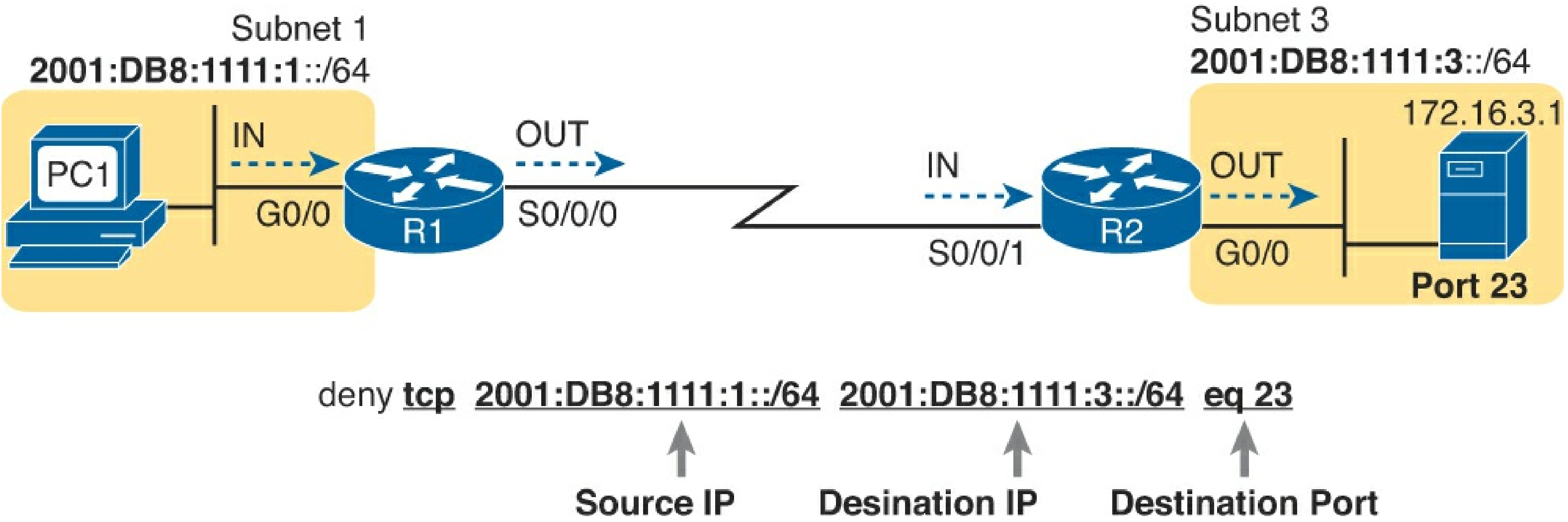

Subnet 1
2001:DB8:1111:1::/64
PC1
IN
G0/0
R1
OUT
S0/0/0
IN
S0/0/1
R2
Subnet 3
2001:DB8:1111:3::/64
172.16.3.1
OUT
G0/0
Port 23
deny tcp 2001:DB8:1111:1::/64 2001:DB8:1111:3::/64 eq 23
Source IP
Desination IP
Destination Port

Figure 16-19. Filtering IPv6 Packets Based on Destination Port

Before reading more about troubleshooting, take a closer look at the one-line ACL example. The address ranges are based on the IPv6 prefix (subnet) as calculated based on the address and prefix length. As a result, this ACL defines a source address range of all addresses in subnet 1 (2001:DB8:1111:1::/64) and a destination address range of all addresses in subnet 3 (2001:DB8:1111:3::/64). It also lists a destination port of 23 (Telnet). So, with a deny action, this ACL command would discard IPv6 Telnet traffic.

Now back to troubleshooting. In short, when you see symptoms that look like a routing problem, check to see whether any IPv6 ACLs have been enabled. On IPv4 routers, the command to check for any enabled ACLs is **show ip interface**. So, with IPv6, you use the command **show ipv6 interface**. Example 16-8 shows this command applied to a router, with the highlighted line noting the enabled IPv6 ACL.

Example 16-8. The show ipv6 interface **Command on Router R2**

Click here to view code image

```
R2# show ipv6 interface
Serial0/0/0 is up, line protocol is up
IPv6 is enabled, link-local address is FE80::FF:FE00:1
No Virtual link-local address(es):
Global unicast address(es):
2001:DB8:1:12::1, subnet is 2001:DB8:1:12::/64
Joined group address(es):
FF02::1
FF02::2
FF02::5
FF02::1:FF00:1
MTU is 1500 bytes
ICMP error messages limited to one every 100 milliseconds
ICMP redirects are enabled
ICMP unreachables are sent
Output features: Access List
Outgoing access list book
! Lines omitted for brevity
```

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 16-2 lists these key topics and where each is discussed.

Table 16-2. Key Topics for Chapter 16

Key Topic Element	Description	Page Number
Table 16-1	IPv6 address types	474
Figure 16-5	Comparisons of IPv4 DHCP versus IPv6 stateful DHCP	475
Figure 16-7	Details of source of host IPv6 settings when using SLAAC	476
List	Steps to build an address using SLAAC and EUI-64	477
Figure 16-8	Concepts behind using SLAAC and EUI-64	477
List	IPv6 addressing and routing configuration steps	477
List	Working with hosts in IPv6 networks	483
List	Working with routers in IPv6 networks	484
List	Working with filtering in IPv6 networks	484
Figure 16-13	Specific host settings to compare to other devices when troubleshooting	485
List	Categories of issues that prevent an IPv6 host from pinging its default router	486
List	Categories of issues that prevent IPv6 hosts from using DNS server functions	487
List	Requirements for DHCPv6 to work correctly	488
Figure 16-16	DHCPv6 relay agent configuration in a router	489
List	Reasons why the NDP RS/RA process would fail between a host and router	490
List	Possible reasons for IPv6 routing problems	491

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix D, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix E, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22 directs you in how to use these terms for late-stage preparation for the exam.

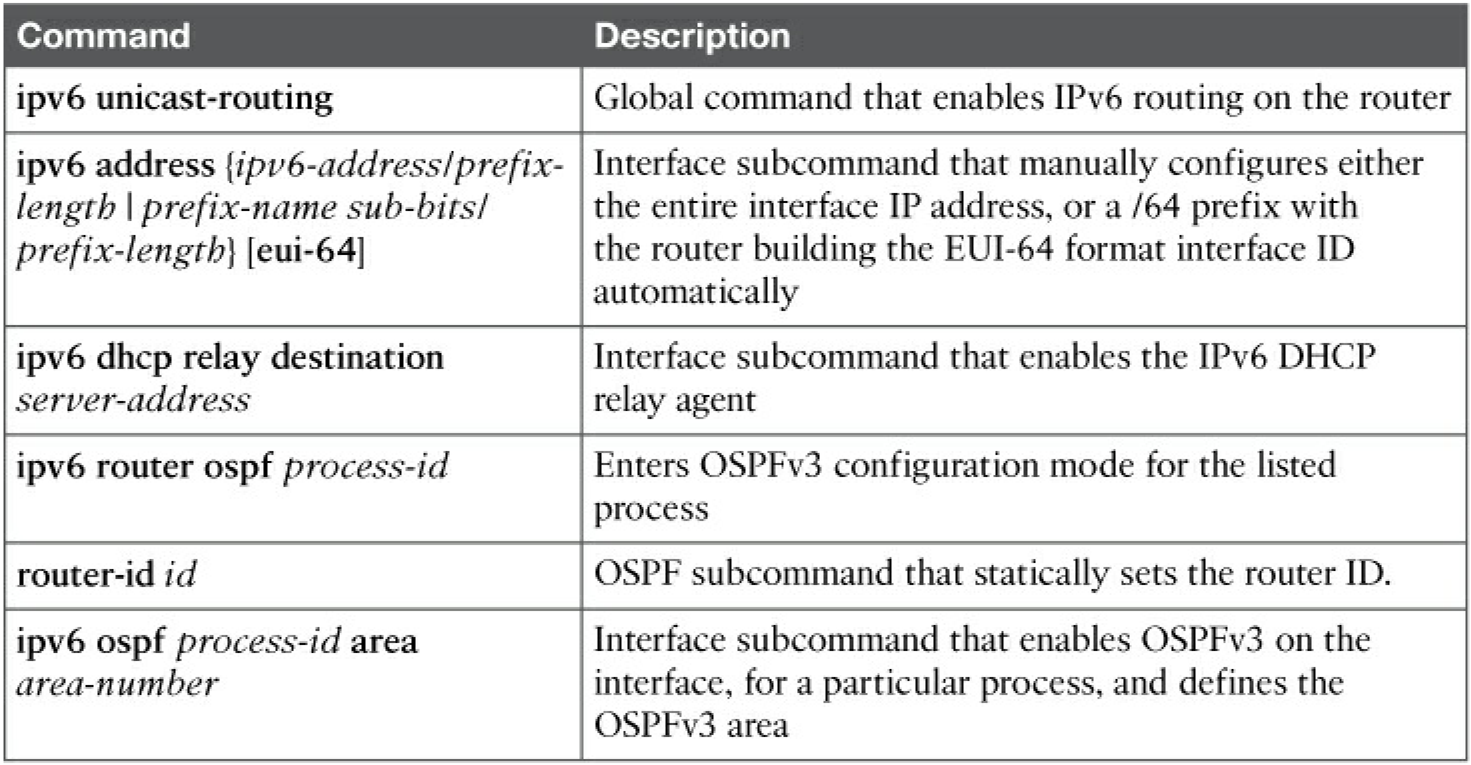
Neighbor Discovery Protocol (NDP) Router Solicitation (RS)
Router Advertisement (RA)
Neighbor Solicitation (NS)
Neighbor Advertisement (NA)
stateless address autoconfiguration (SLAAC)

stateful DHCPv6
stateless DHCPv6
global unicast address
unique local unicast address
link-local address
EUI-64
dual stack

Command Reference to Check Your Memory

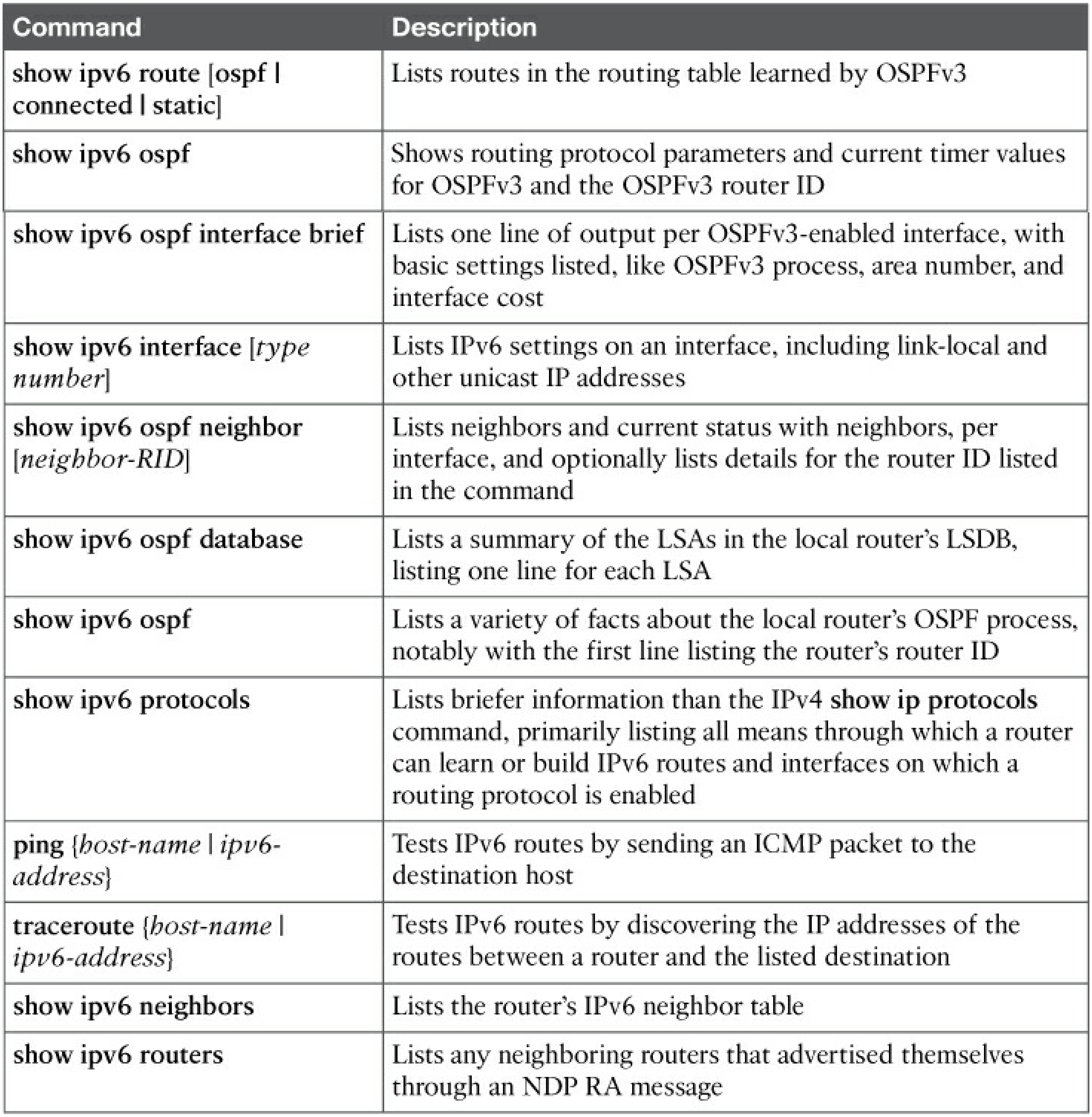
Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To check to see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table with a piece of paper, read the descriptions on the right side, and see whether you remember the command.

Table 16-3. Chapter 16 Configuration Command Reference



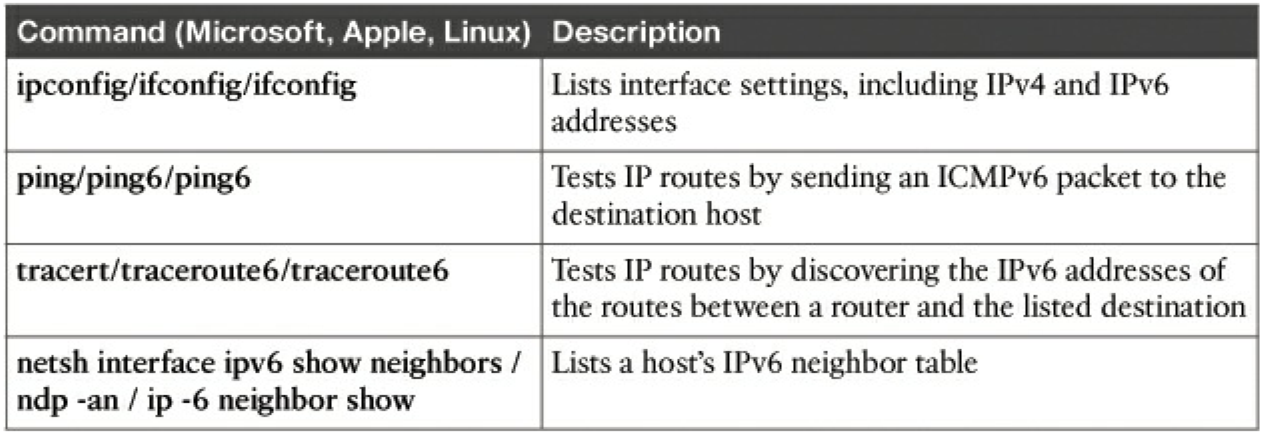
Command	Description
ipv6 unicast-routing	Global command that enables IPv6 routing on the router
ipv6 address {*ipv6-address*/*prefix-length* | *prefix-name sub-bits*/*prefix-length*} [**eui-64**]	Interface subcommand that manually configures either the entire interface IP address, or a /64 prefix with the router building the EUI-64 format interface ID automatically
ipv6 dhcp relay destination *server-address*	Interface subcommand that enables the IPv6 DHCP relay agent
ipv6 router ospf *process-id*	Enters OSPFv3 configuration mode for the listed process
router-id *id*	OSPF subcommand that statically sets the router ID.
ipv6 ospf *process-id* **area** *area-number*	Interface subcommand that enables OSPFv3 on the interface, for a particular process, and defines the OSPFv3 area

Table 16-4. Chapter 16 EXEC Command Reference



Command	Description
show ipv6 route [**ospf** | **connected** | **static**]	Lists routes in the routing table learned by OSPFv3
show ipv6 ospf	Shows routing protocol parameters and current timer values for OSPFv3 and the OSPFv3 router ID
show ipv6 ospf interface brief	Lists one line of output per OSPFv3-enabled interface, with basic settings listed, like OSPFv3 process, area number, and interface cost
show ipv6 interface [*type number*]	Lists IPv6 settings on an interface, including link-local and other unicast IP addresses
show ipv6 ospf neighbor [*neighbor-RID*]	Lists neighbors and current status with neighbors, per interface, and optionally lists details for the router ID listed in the command
show ipv6 ospf database	Lists a summary of the LSAs in the local router's LSDB, listing one line for each LSA
show ipv6 ospf	Lists a variety of facts about the local router's OSPF process, notably with the first line listing the router's router ID
show ipv6 protocols	Lists briefer information than the IPv4 **show ip protocols** command, primarily listing all means through which a router can learn or build IPv6 routes and interfaces on which a routing protocol is enabled
ping {*host-name* | *ipv6-address*}	Tests IPv6 routes by sending an ICMP packet to the destination host
traceroute {*host-name* | *ipv6-address*}	Tests IPv6 routes by discovering the IP addresses of the routes between a router and the listed destination
show ipv6 neighbors	Lists the router's IPv6 neighbor table
show ipv6 routers	Lists any neighboring routers that advertised themselves through an NDP RA message

Table 16-5. Chapter 16 Host Command Reference



Command (Microsoft, Apple, Linux)	Description
ipconfig/ifconfig/ifconfig	Lists interface settings, including IPv4 and IPv6 addresses
ping/ping6/ping6	Tests IP routes by sending an ICMPv6 packet to the destination host
tracert/traceroute6/traceroute6	Tests IP routes by discovering the IPv6 addresses of the routes between a router and the listed destination
netsh interface ipv6 show neighbors / ndp -an / ip -6 neighbor show	Lists a host's IPv6 neighbor table

Chapter 17. Implementing OSPF for IPv6

This chapter covers the following exam topics:

IP Routing Technologies

- Configure and verify OSPF (single area)
    - neighbor adjacencies
    - OSPF states
    - Discuss Multi area
    - Configure OSPF v3
    - Router ID
    - LSA types
- Differentiate methods of routing and routing protocols
    - metric
    - next hop

Troubleshooting

- Troubleshoot and Resolve OSPF problems
    - Neighbor adjacencies
    - Hello and Dead timers
    - OSPF area
    - Interface MTU
    - Network types
    - Neighbor states
    - OSPF topology database

By this point in your reading, you should know a lot about OSPF Version 3 (OSPFv3), but for a couple of different reasons. First, the ICND1 book and the CCENT exam include the basics of OSPFv3 concepts, configuration, and verification. Beyond that, OSPFv3 works much like OSPFv2 in many ways, and this book's Chapters 8, "Implementing OSPF for IPv4," and 11, "Troubleshooting IPv4 Routing Protocols," took the discussion of OSPFv2 to a deeper level.

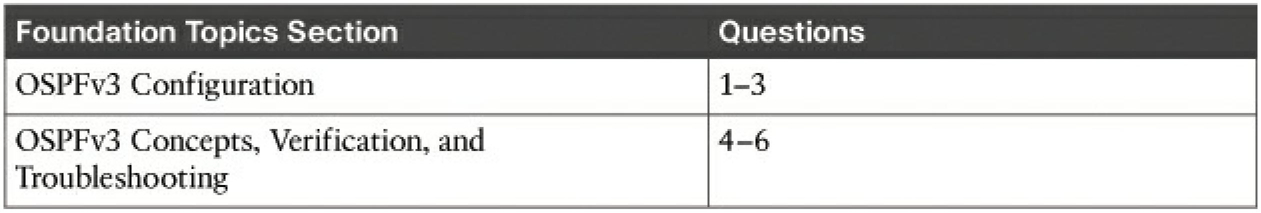
This chapter pulls all the OSPFv3 puzzle pieces together by taking advantage of all the other material on both OSPFv2 and OSPFv3. Because you have already read about almost every bit of the conceptual knowledge required for this chapter's OSPFv3 discussion, this chapter moves immediately to the configuration in the first major section. This initial section both reviews the ICND1 OSPFv3 configuration topics and examines them more closely. It also introduces all the new configuration topics for this chapter.

The second major section pulls many OSPF concepts together by using verification commands. This section discusses and reminds you of both OSPFv2 and OSPFv3 topics, using the verification commands to demonstrate how the routers implement those concepts. At the same time, the discussion includes a list of common root causes of OSPFv3 problems and explains how to recognize those problems.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 17-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
OSPFv3 Configuration	1–3
OSPFv3 Concepts, Verification, and Troubleshooting	4–6

1. An engineer wants to set the OSPFv3 router ID for router R1. Which of the following answers could affect R1's choice of OSPFv3 router ID?

    a. The **ipv6 address** command on interface Gigabit0/0

    b. The **ip address** command on interface Serial0/0/1

    c. The **ospf router-id** command in OSPFv3 configuration mode

    d. The **ipv6 address** command on interface loopback2

2. Router R1 has a Serial0/0/0 interface with address 2001:1:1:1::1/64, and a G0/0 interface with address 2001:2:2:2::1/64. The OSPFv3 process uses process ID 1. Which of the following OSPFv3 configuration commands

enable OSPFv3 on R1's G0/0 interface and places it into area 0?

- **a.** A **network 2001:1:1:1:1::/64 1 area 0** command in router configuration mode
- **b.** An **ipv6 ospf 1 area 0** command in G0/0 interface configuration mode
- **c.** A **network 2001:1:1:1::/64 1 area 0** command in router configuration mode
- **d.** An **ospf 1 area 0** command in G0/0 interface configuration mode

3. An enterprise uses a dual-stack model of deployment for IPv4 and IPv6, using OSPF as the routing protocol for both. Router R1 has IPv4 and IPv6 addresses on its G0/0 and S0/0/0 interfaces only, with OSPFv2 and OSPFv3 enabled on both interfaces for area 0 and the router ID explicitly set for both protocols. Comparing the OSPFv2 and OSPFv3 configuration, which of the following statements is true?

- **a.** The OSPFv3 configuration, but not OSPFv2, uses the **router-id** *router-id* router subcommand.
- **b.** Both protocols use the **router-id** *router-id* router subcommand.
- **c.** Both protocols use the **network** *network-number wildcard* **area** *area-id* router subcommand.
- **d.** The both protocols use the **ipv6 ospf** *process-id* **area** *area-id* interface subcommand.

4. R1 and R2 are routers that connect to the same VLAN. Which of the answers lists an item that can prevent the two routers from becoming OSPFv3 neighbors? (Choose three answers.)

- **a.** Mismatched Hello timers
- **b.** Mismatched process IDs
- **c.** IPv6 addresses in different subnets
- **d.** Equal router IDs
- **e.** One passive router interface (used on this link)

5. The example shows an excerpt from the **show ipv6 route ospf** command on a router (R1). Which of the answers are correct about the interpretation of the meaning of the output of this command? (Choose two answers.)

```
R1# show ipv6 route ospf
OI 2001:DB8:1:4::/64 [110/129]
via FE80::FF:FE00:1, Serial0/0/1
```

- **a.** 110 is the metric for the route.
- **b.** S0/0/1 is an interface on R1.
- **c.** FE80::FF:FE00:1 is a link-local address on R1.
- **d.** OI means that the route is an interarea OSPF route.

6. Router R1 has been configured as a dual-stack IPv4/IPv6 router, using interfaces S0/0/0, S0/0/1, and GigabitEthernet0/1. As a new engineer hired at the company, you do not know whether any of the interfaces are passive. Which of the following commands lets you find whether G0/1 is passive, either by the command listing that fact or by that command leaving passive interfaces out of its list of interfaces?

- **a. show ipv6 ospf interface brief**
- **b. show ipv6 protocols**
- **c. show ipv6 ospf interface G0/1**
- **d. show ipv6 ospf interface passive**

Answers to the "Do I Know This Already?" quiz:

1 B **2** B **3** B **4** A, D, and E **5** B and D **6** C

Foundation Topics

OSPFv3 Configuration

Cisco expects you to know some OSPFv3 details for the ICND1 exam, but for the ICND2 exam, you should both remember all the ICND1 OSPFv3 topics plus add some new knowledge and skills. This first of two major sections in the chapter looks at OSPFv3 configuration, reviewing ICND1 configuration topics and adding some for ICND2. The new topics include multi-area OSPFv3 configuration, setting OSPF costs, load balancing, and injecting default routes.

OSPFv3 ICND1 Configuration Review

As a first step, review the OSPFv3 configuration that was part of your study for the ICND1 exam topics. The following list summarizes the configuration steps for the OSPFv3 configuration included in ICND1:

Key Topic

Step 1. Create an OSPFv3 process number and enter OSPF configuration mode for that process using the **ipv6 router ospf** *process-id* global command.

Step 2. Ensure that the router has an OSPF router ID, through either:

- **A.** Configuring the **router-id** *id-value* router subcommand
- **B.** Configuring an IP address on a loopback interface (chooses the highest IP address of all working loopbacks)
- **C.** Relying on an interface IP address (chooses the highest IP address of all working nonloopbacks)

Step 3. Configure the **ipv6 ospf** *process-id* **area** *area-number* command on each interface on which OSPFv3 should be enabled, to both enable OSPFv3 on the interface and set the area number for the interface.

Step 4. (Optional) Configure any OSPFv3 interfaces as passive if no neighbors can or should be discovered on the interface, using the **passive-interface** *type number* interface subcommand.

Before looking at the multi-area configuration, bear with me on a brief tangent about the exam topics for OSPF. Frankly, the OSPF exam topics (at the time of this writing) skirt around the dividing line of whether you need to know how to configure multi-area OSPF (both OSPFv2 and OSPFv3). The configuration-oriented exam topics clearly imply single-area configuration only, although the troubleshooting topics may imply that you need knowledge of multi-area configuration. The good news is this: Once you understand multi-area concepts and single-area configuration, adding multi-area configuration is incredibly simple. So, this topic shows the multi-area details, just in case you need them for the exam.

Example Multi-Area OSPFv3 Configuration

Many OSPFv3 facts listed in this chapter work like the same idea in OSPFv2. So, to make those similarities pop even more, this configuration section uses a multi-area configuration example with the exact same internetwork topology as the multi-area example shown in the OSPFv2 chapter (Chapter 8, "Implementing OSPF for IPv4").

Figure 17-1 begins to describe the design, before getting into the configuration, showing the IPv6 subnets. The figure does not show the individual router IPv6 addresses, to reduce clutter, but to make the addresses easier to recognize, the addresses all end with the same number as the router. For example, all five of router R1's interface addresses end with 1.

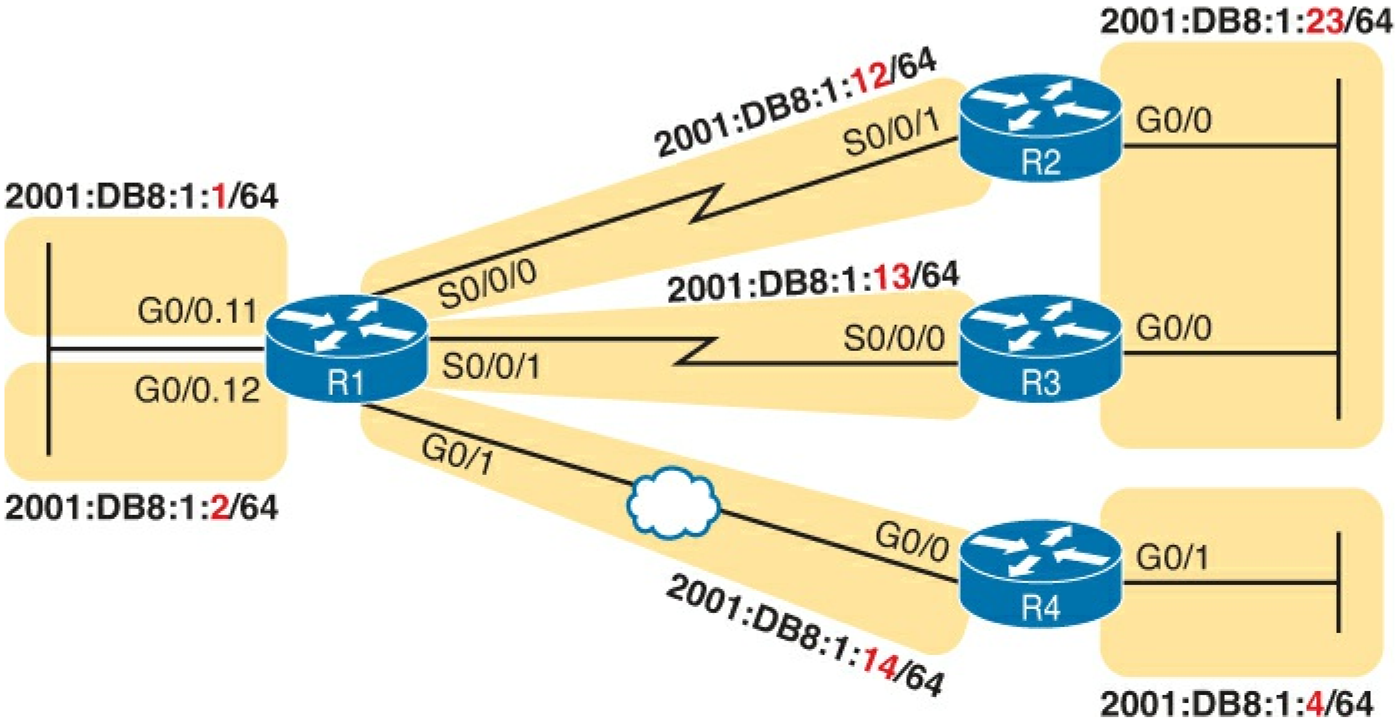


Figure 17-1. The Internetwork for an Example Multi-Area OSPFv3 Configuration

Figure 17-2 next shows the OSPFv3 area design. For those of you with an excellent memory, the design is literally identical to Chapter 8's Figure 8-12, which defined the area design for that chapter's multi-area design example. The design makes R2 and R3 internal routers inside area 23, R4 an internal router inside area 4, and R1 an Area Border Router (ABR) connected to all three areas.

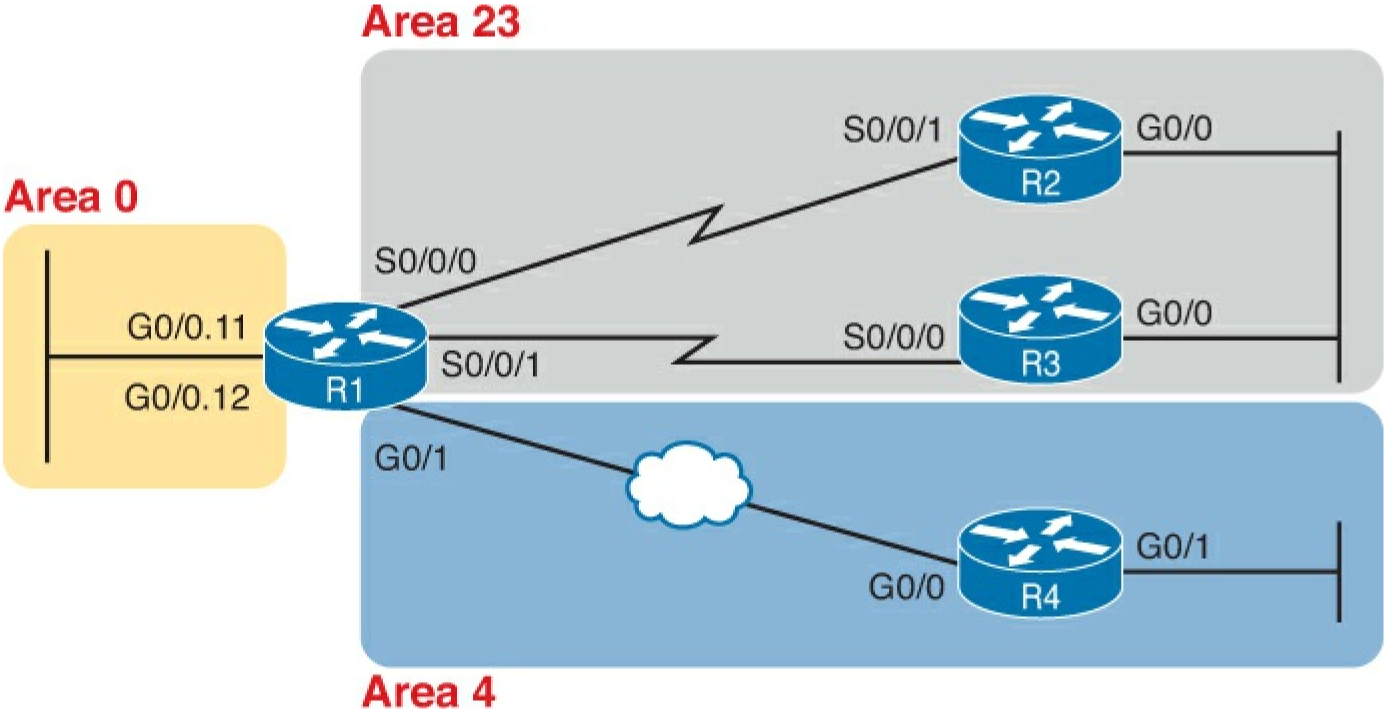


Figure 17-2. Area Design for the Multi-Area OSPFv3 Example

Single Area Configuration on the Three Internal Routers

The configurations on the three internal routers in this example review ICND1-level single-area OSPF configuration. In a multi-area OSPF design, the configuration on any internal routers—routers for which all interfaces connect to a single area—looks like a single-area configuration because all the interfaces are placed into one area.

Example 17-1 begins the example with R2’s complete IPv6 configuration, including OSPFv3. In other words, all the commands needed on R2 to add IPv6 support are in the example. Note that for OSPFv3 in particular, the example shows the following actions, as highlighted in the example:

1. Creates an OSPFv3 process with process ID 2
2. Defines the OSPFv3 RID explicitly as 2.2.2.2
3. Enables OSPFv3 process 2 on two interfaces, putting both in area 23

Example 17-1. IPv6 and OSPFv3 Configuration on Internal Router R2

Click here to view code image

```
ipv6 unicast-routing
!
interface GigabitEthernet0/0
mac-address 0200.0000.0002
ipv6 address 2001:db8:1:23::2/64
ipv6 ospf 2 area 23
!
interface serial 0/0/1
ipv6 address 2001:db8:1:12::2/64
ipv6 ospf 2 area 23
!
ipv6 router ospf 2
router-id 2.2.2.2
```

First, focus on the two commands that should be in every OSPFv3 configuration: the **ipv6 router ospf** *process-id* global command and the **ipv6 ospf** *process-id* **area** *area-id* interface subcommand. The first command creates the OSPFv3 process by number. The second command, one per interface, enables that OSPFv3 process on the interface and assigns the area number. In this case, R2 has a process ID of 2, with both interfaces assigned to area 23.

Next, consider one completely optional feature: OSPFv3 passive interfaces. This feature uses the same concepts and literally the exact same command syntax as OSPFv2. If a router should not form neighbor relationships on an interface, that interface may be made passive. In this case, R2 should find at least one OSPFv3 neighbor on each of its two interfaces, so the configuration does not include the **passive-interface** command at all.

Finally, OSPFv3 follows the same rules as OSPFv2 when setting the OSPFv3 router ID (RID). In this case, R2 sets its RID using the OSPFv3 **router-id** command, but you should be ready to understand all three ways.

Now on to the configuration on R3, which should have a very similar OSPFv3 configuration compared to router R2. Both are internal routers in area 23, and both have at least one neighbor off their two interfaces, respectively, so both cannot make either of their interfaces passive. Also, just to make the point that OSPFv3 neighbors may use different process ID values, R3 uses OSPFv3 process ID 3, while R2 uses 2. Example 17-2 shows the resulting configuration.

Example 17-2. IPv6 and OSPFv3 Configuration on R3

Click here to view code image

```
ipv6 unicast-routing
!
interface GigabitEthernet0/0
mac-address 0200.0000.0003
ipv6 address 2001:db8:1:23::3/64
ipv6 ospf 3 area 23
!
interface serial 0/0/0
ipv6 address 2001:db8:1:13::3/64
ipv6 ospf 3 area 23
!
ipv6 router ospf 3
router-id 3.3.3.3
```

Moving on to R4, in Example 17-3, the configuration differs slightly from the previous two routers. First, R4 can make its G0/1 interface passive because R4 expects to create no OSPFv3 neighbor relationships off that LAN interface. R4 also uses a different OSPFv3 process ID.

> **Note**
>
> Although these examples use different OSPFv3 process IDs, to show that such a choice causes no problems, most enterprises would use the same process ID value on all routers for consistency.

Example 17-3. IPv6 and OSPFv3 Configuration on R4

Click here to view code image

```
ipv6 unicast-routing
!
interface GigabitEthernet0/0
mac-address 0200.0000.0004
ipv6 address 2001:db8:1:14::4/64
ipv6 ospf 4 area 4
!
interface GigabitEthernet0/1
ipv6 address 2001:db8:1:4::4/64
ipv6 ospf 4 area 4
!
ipv6 router ospf 4
router-id 4.4.4.4
passive-interface gigabitethernet0/1
```

Adding Multi-Area Configuration on the Area Border Router

The configuration for multi-area OSPF is just as anticlimactic for OSPFv3 as it was for OSPFv2. Multi-area OSPF may lead to some interesting design discussions when deciding which links to put in which areas. Once decided, the configuration is just a matter of reading the documentation correctly and typing the correct area number into the **ipv6 ospf** *process-id* **area** *area-id* interface subcommand.

In this example, ABR R1 has an OSPFv3 process (process ID 1), with OSPFv3 enabled on five interfaces, as follows, to match earlier Figure 17-2:

Area 0: G0/0.11 and G0/0.12

Area 23: S0/0/0 and S0/0/1

Area 4: G0/1

To be clear, nothing in R1's configuration mentions multi-area or ABR—R1 simply acts as an ABR because its configuration puts some interfaces in area 0 and others in other nonbackbone areas. Example 17-4 shows the configuration.

Key Topic

Example 17-4. IPv6 and OSPFv3 Configuration on ABR R1

Click here to view code image

```
ipv6 unicast-routing
!
interface GigabitEthernet0/0
mac-address 0200.0000.0001
!
interface GigabitEthernet0/0.11
encapsulation dot1q 11
ipv6 address 2001:db8:1:1::1/64
ipv6 ospf 1 area 0
!
interface GigabitEthernet0/0.12
encapsulation dot1q 12
ipv6 address 2001:db8:1:2::1/64
ipv6 ospf 1 area 0
!
interface GigabitEthernet0/1
ipv6 address 2001:db8:1:14::1/64
ipv6 ospf 1 area 4
!
interface serial 0/0/0
ipv6 address 2001:db8:1:12::1/64
ipv6 ospf 1 area 23
!
interface serial 0/0/1
ipv6 address 2001:db8:1:13::1/64
ipv6 ospf 1 area 23
!
ipv6 router ospf 1
router-id 1.1.1.1
```

Other OSPFv3 Configuration Settings

The example completes all the review of ICND1 OSPFv3 configuration, while adding that small bit of information about multi-area configuration. The next few short configuration topics take some other OSPF features discussed for OSPFv2 back in Chapter 8 and discusses how to configure those for OSPFv3. And as usual, the details are nearly identical.

Setting OSPFv3 Interface Cost to Influence Route Selection

OSPFv3 works much like OSPFv2 in how it calculates the metric for a route, with some slight differences with the concepts, configuration commands, and verification commands.

To review the concepts, as discussed back in the OSPFv2 chapter (Chapter 8), shortest path first (SPF) on a router finds all possible routes for a subnet. Then, it adds the OSPF interface cost for all outgoing interfaces in a route.

For instance, Figure 17-3 repeats a figure from Chapter 8, changed slightly to now show an IPv6 subnet. The figures shows a single-area design in which R1 finds three possible routes to reach subnet 33 (2001:DB8:1:33::/64), the middle route having the lowest cost.

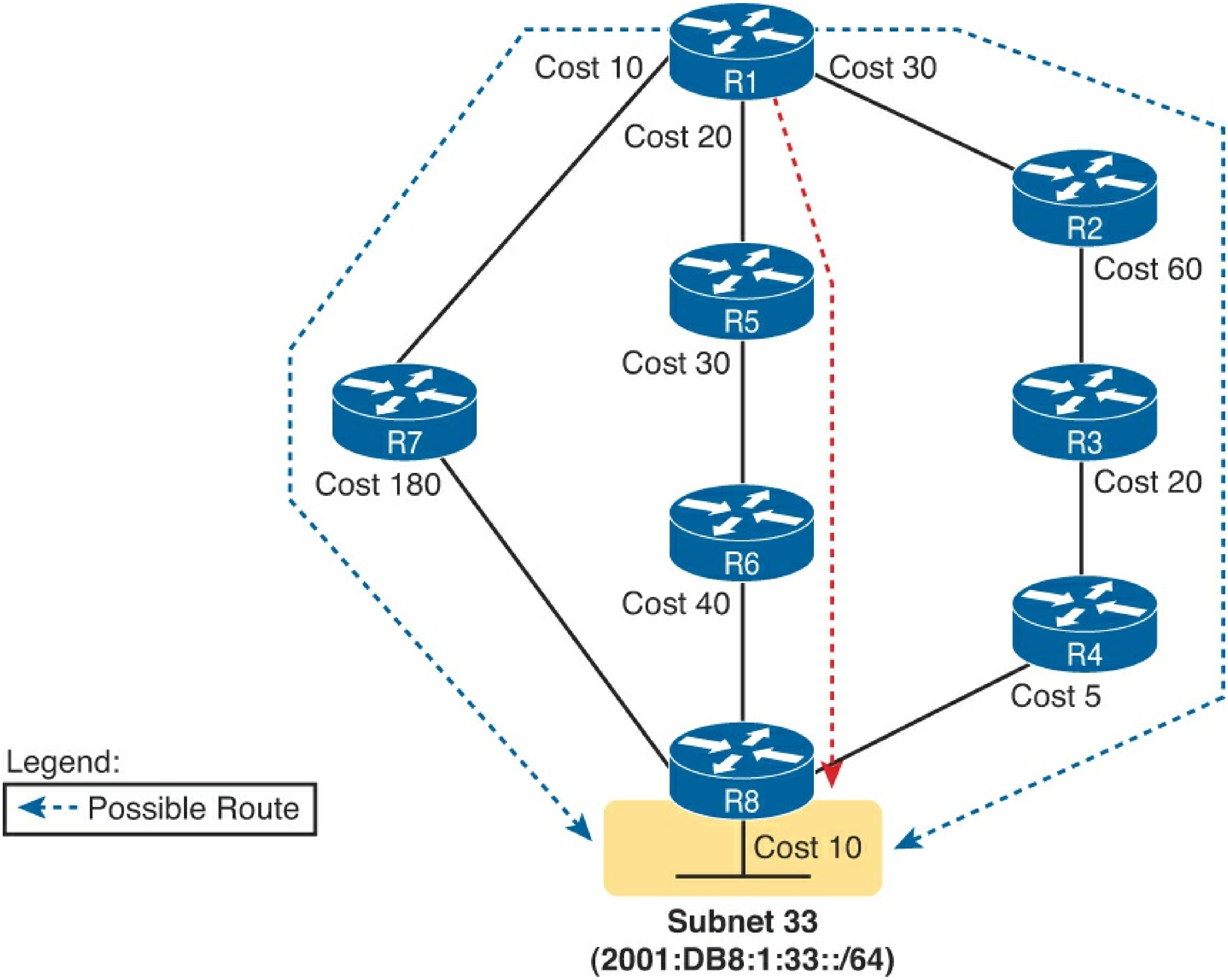


Figure 17-3. SPF Tree to Find R1's Route to 2001:DB8:1:33::/64

To influence the metric for the route, OSPFv3 gives us a few ways to change an interface's OSPFv3 cost, with the same basic rules as OSPFv2, as summarized in this list:

Key Topic

1. Set the cost explicitly using the **ipv6 ospf cost** *x* interface subcommand to a value between 1 and 65,535, inclusive.
2. Change the interface bandwidth with the **bandwidth** *speed* command, with speed being a number in kilobits per second (Kbps), and let the router calculate the value based on the OSPFv3 **reference-bandwidth** / **interface-bandwidth**.
3. Change the reference bandwidth router OSPFv3 subcommand **auto-cost reference-bandwidth** *ref-bw*, with a unit of megabits per second (Mbps).

OSPF Load Balancing

OSPFv3 and OSPFv2 follow the same concept, with the exact same configuration command, to effect equal-cost load balancing.

When OSPFv3 on a router calculates multiple equal-metric routes to reach one subnet, the router can put multiple equal-cost routes in the routing table. The OSPFv3 **maximum-paths** *number* router subcommand defines just how many such routes OSPFv3 will add to the IPv6 routing table. For example, if an internetwork has six possible routes for some subnet, and all have the exact same metric, and the engineer wants all routes to be used, he could configure the router with the **maximum-paths 6** subcommand under the **ipv6 router ospf** command.

Injecting Default Routes

Finally, with yet another OSPFv3 feature that works very much like OSPFv2, OSPFv3 supports a router's capability to advertise a default route with OSPFv3. This function allows one router to have a default route and then basically tell all other routers, "Hey, if you need a default route, send packets to me, and I'll send them with my good default route."

One classic case for using a routing protocol to advertise a default route has to do with an enterprise's connection to the Internet. If a company has one IPv6-enabled Internet connection, that one router can use a default IPv6 route to route all IPv6 Internet traffic out that one link. But the rest of the enterprise's routers need to send their Internet traffic to this one router, so the enterprise engineer uses these design goals:

- All routers learn specific routes for subnets inside the company, so a default route is not needed for destinations inside the company.
- The one router that connects to the Internet has a static default IPv6 route that points all IPv6 traffic (that does not match any other IPv6 route) into the Internet.
- All routers learn (by using OSPFv3) a default route from the Internet-facing router so that all IPv6 packets going to the Internet first go to this one router.

Figure 17-4 shows the ideas of how the routing information is propagated from the Internet-facing router (R1) to the other routers in the company. In this case, a company connects to an ISP with their router R1. Router R1 uses the OSPFv3 **default-information originate** command in OSPFv3 configuration mode; this command is literally the same command used for OSPFv2 (Step 1). As a result, R1 advertises a default route to the other OSPFv3 routers (Step 2). (The prefix for the default route with IPv6 is ::/0, with a prefix length 0, somewhat like the 0.0.0.0/0 used with IPv4.)

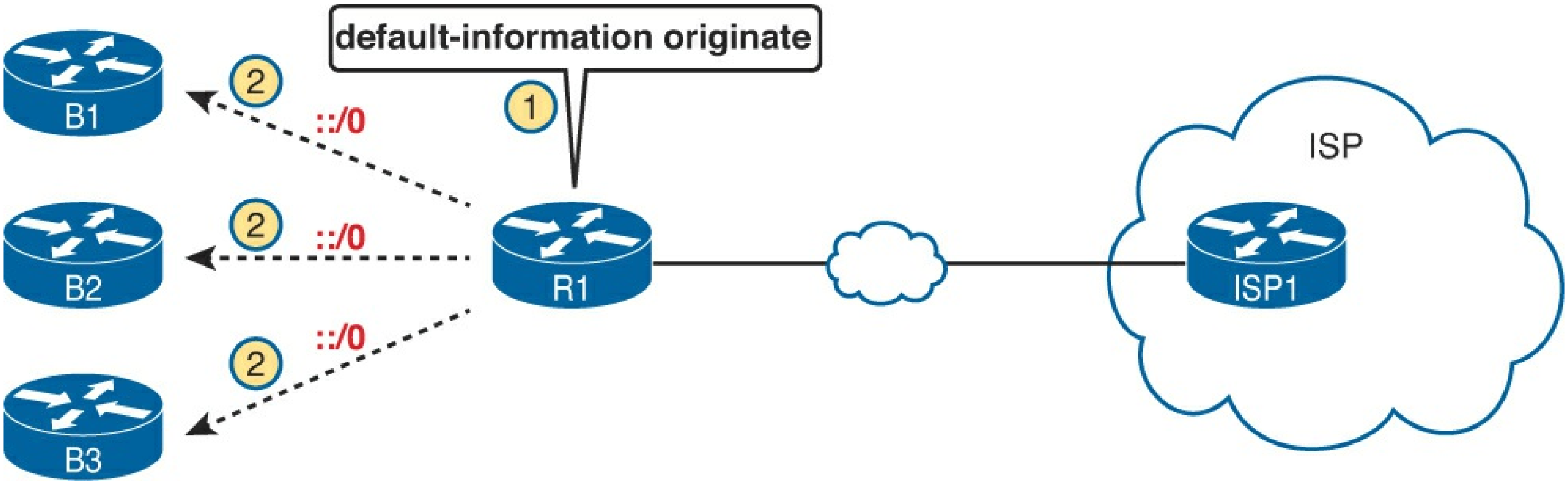


Figure 17-4. Using OSPFv3 to Advertise a Default Route

Once the process in Figure 17-4 completes, the three routers on the left each have a default route. Their default routes point to R1 as the next-hop router so that all traffic destined for the Internet first goes to R1 and then out to the ISP.

That completes the discussion of new configuration for OSPFv3. The next section covers various OSPFv3 concepts, including verification and troubleshooting.

OSPF Concepts, Verification, and Troubleshooting

To the depth discussed for CCNA Routing and Switching, OSPFv3 and OSPFv2 behave very much like each other. So far, between this book and your reading for the ICND1 exam, you should have already read about all the equivalent OSPFv2 concepts, seen the OSPFv2 verification commands, and seen many OSPFv2 troubleshooting issues. This second major section of the chapter just needs to show where OSPFv3 uses the same concepts and show where, in those rare cases, OSPFv3 differs from OSPFv2.

For instance, to the depth discussed in these books, OSPFv3 works much like OSPFv2 with regard to:

Key Topic

- Area design and the related terms.
- The configuration idea of enabling the routing process, per interface, for an area.
- The neighbor discovery process with Hello messages.
- Transitioning through neighbor states and the topology exchange process.
- The use of full and 2-way as the normal stable state for working neighbor relationships, with other states being either temporary or pointing to some problem with the neighbor.
- The general ideas behinds LSA Types 1, 2, and 3 and the link-state database (LSDB).
- SPF and how it uses interface cost to calculate metrics.
- Messages are sent to reserved multicast addresses (FF02::5 for all OSPF routers, FF02::6 for all DR and BDR routers), similar to OSPFv2's use of 224.0.0.5 and 224.0.0.6.

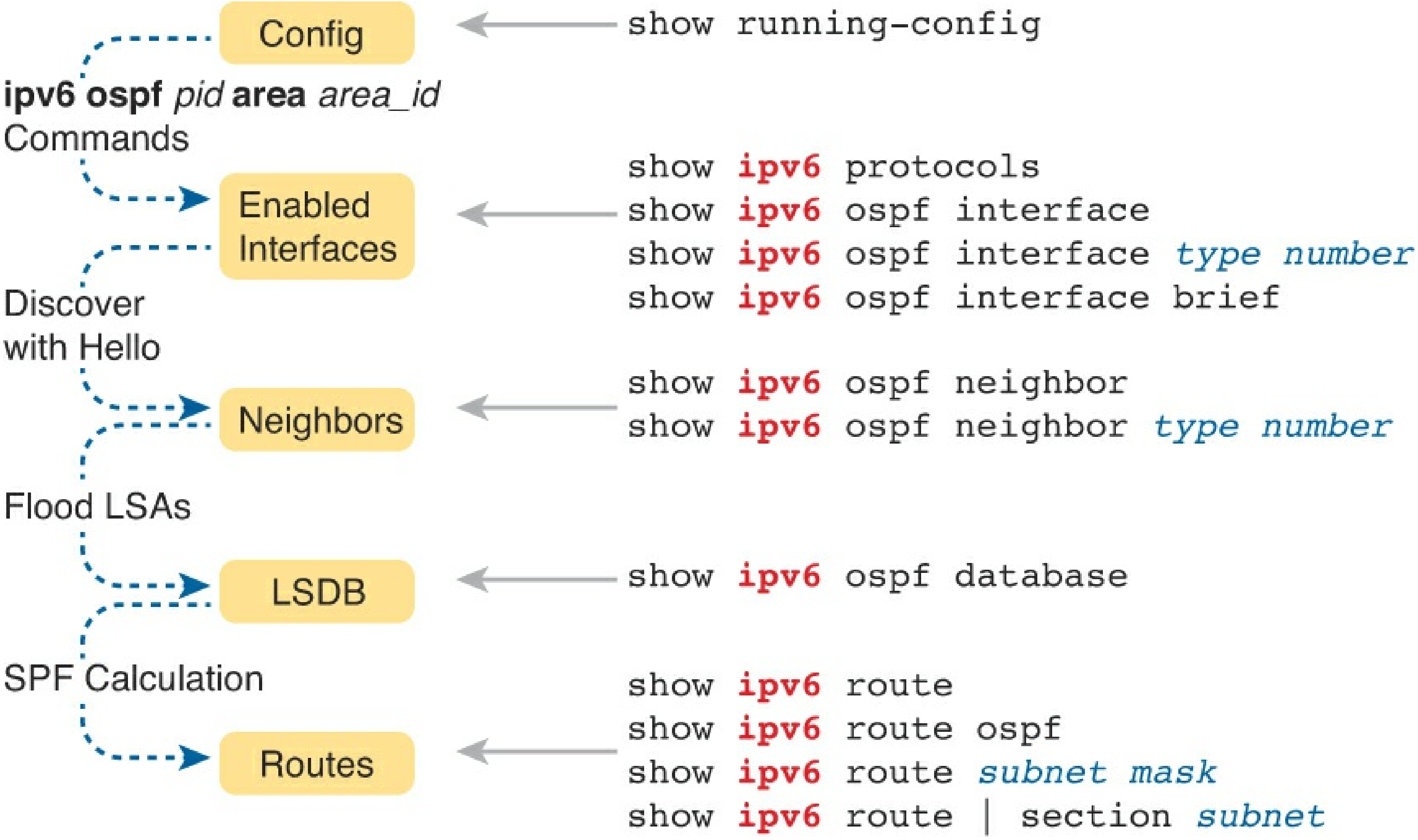
So, what is different between the two? The next list mentions a few differences. However, note that many of the differences happen to be outside the scope of the coverage of topics in this book:

Key Topic

- The name of the Type 3 LSA.
- That OSPFv3 neighbors do not have to have IPv6 addresses in the same IPv6 subnet, whereas OSPFv2 neighbors must be in the same IPv4 subnet.
- New LSA types used by OSPFv3 but not by OSPFv2 (also beyond scope).
- The details defined inside LSA types 1, 2, and 3 differ (details beyond the scope of this book).

As you can see, the list of differences is relatively short.

Because of the many similarities between OSPFv3 and OSPFv2, Cisco keeps the verification commands similar too. Figure 17-5 summarizes the OSPFv3 verification commands relative to the kinds of information they show. Note that all the commands that list **ipv6** can be changed to **ip** to create the exact syntax of the matching OSPFv2 **show** command.



```
show running-config

show ipv6 protocols
show ipv6 ospf interface
show ipv6 ospf interface type number
show ipv6 ospf interface brief

show ipv6 ospf neighbor
show ipv6 ospf neighbor type number

show ipv6 ospf database

show ipv6 route
show ipv6 route ospf
show ipv6 route subnet mask
show ipv6 route | section subnet
```

Figure 17-5. Reference of OSPFv3 Verification Commands

When a router first brings up the OSPFv3 process, IOS reads the OSPFv3 configuration and enables OSPFv3 on interfaces. So, this section begins by discussing OSPFv3 interface verification and troubleshooting. Following that, the discussion moves on to OSPFv3 neighbors, then to the OSPFv3 topology database, and finally to OSPFv3 routes added to the IPv6 routing table.

> **Note**
>
> All the troubleshooting examples in the rest of this chapter use routers R1, R2, R3, and R4 from the multi-area configuration example earlier in this chapter. Look back to Figures 17-1 and 17-2 for a reference to the topology and area diagrams for this network.

OSPFv3 Interfaces

The style of OSPFv3 configuration clearly identifies on which interfaces the OSPFv3 process should be working. The **ip ospf** *process-id* **area** *area-id* interface subcommand basically means "run OSPFv3 on this interface." A quick scan of the interface in the output of the **show running-config** command can identify the interfaces and the area number for each.

The next few pages first takes a look at a few other methods of verifying OSPFv3 interfaces, and then the discussion turns to some OSPFv3 interface troubleshooting tips.

Verifying OSPFv3 Interfaces

Suppose that, from studying, you have both seen and practiced OSPFv3 configuration and you feel confident about the configuration. Then, on the exam, you happen to get a simlet question on OSPFv3. Unfortunately, like many simlet questions, the question does not let you into enable mode, so you cannot see the configuration! A **show running-config** command plus your good configuration skills would let you answer any question, but you cannot see the config. How can you find out, for example, on which interfaces the OSPFv3 process has been enabled?

Three commands tell you something about interfaces enabled for OSPFv3: **show ipv6 protocols**, **show ipv6 ospf interface brief**, and **show ipv6 ospf interface**. All three commands list the interfaces on which OSPFv3 has been enabled. The first two commands list the information briefly, and the third command lists many, many lines of output per interface. (If you want a quick answer, use either of the first two commands.)

Note that all three of these commands list both passive and nonpassive OSPFv3 interfaces—a handy fact to know when troubleshooting neighbor issues. To see the effect, look at Example 17-5. But first, note that before gathering the output in the example, the command **passive-interface gigabitethernet0/0.11** was added to R1's OSPFv3 process.

Example 17-5. Verifying OSPFv3 Interfaces and Related Parameters

Click here to view code image

```
R1# show ipv6 protocols
IPv6 Routing Protocol is "connected"
IPv6 Routing Protocol is "ND"
IPv6 Routing Protocol is "ospf 1"
Interfaces (Area 0):
GigabitEthernet0/0.12
GigabitEthernet0/0.11
Interfaces (Area 4):
GigabitEthernet0/1
Interfaces (Area 23):
Serial0/0/1
Serial0/0/0
Redistribution:
None
```

As you can see in the example, the output of the **show ipv6 protocols** command lists all five OSPFv3 interfaces on router R1, including passive interface G0/0.11.

Troubleshooting OSPFv3 Interfaces

Most troubleshooting discussions with OSPFv3 revolve around the problems that can occur between two OSPFv3 neighbors. However, mistakes with interface subcommands can actually cause many of these OSPF neighbor problems. To get the discussions started, just consider the problems that can occur with the interface subcommands mentioned so far in this chapter:

Key Topic

- Configuring the wrong area with the **ip ospf** *process-id* **area** *area-id* interface subcommand prevents neighbor relationships off that interface.
- Making an interface passive to the OSPFv3 process prevents the local router from forming neighbor relationships off that interface.

For the first item in the list, note that all OSPFv3 routers on the same data link need to be assigned to the same area. On the exam, you need to check any information about the intended area design. To find out which interfaces have been assigned to which area, use the **show ipv6 ospf interface** and **show ipv6 ospf interface brief** commands.

As for the issue in making an interface passive to OSPFv3, when a neighbor relationship needs to be made out that interface, the router should not make that interface passive to OSPFv3. Note that only the **show ipv6 ospf interface** command mentions which OSPFv3 interfaces happen to be passive.

Example 17-6 lists two commands that can be helpful for finding both of these problems. Both list area information, but only the second makes mention of an interface being passive.

Example 17-6. Finding OSPFv3 Passive Interfaces on R1

Click here to view code image

```
R1# show ipv6 ospf interface brief
Interface PID Area Intf ID Cost State Nbrs F/C
Gi0/0.12 1 0 16 1 DR 0/0
Gi0/0.11 1 0 17 1 DR 0/0
Gi0/1 1 4 4 1 DR 1/1
Se0/0/1 1 23 7 64 P2P 1/1
Se0/0/0 1 23 6 64 P2P 1/1
```

```
R1# show ipv6 ospf interface G0/0.11
GigabitEthernet0/0.11 is up, line protocol is up
Link Local Address FE80::FF:FE00:1, Interface ID 17
Area 0, Process ID 1, Instance ID 0, Router ID 1.1.1.1
Network Type BROADCAST, Cost: 1
Transmit Delay is 1 sec, State DR, Priority 1
Designated Router (ID) 1.1.1.1, local address FE80::FF:FE00:1
No backup designated router on this network
Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
No Hellos (Passive interface)
! remaining lines omitted for brevity
```

Finally, to see an example of one of the problems, take another look at the configuration for router R4. For the correct configuration in Example 17-3, the engineer made LAN interface G0/1 passive because no other routers existed on that LAN. However, note that R4 uses one Ethernet interface as its WAN interface (G0/0) and one as its LAN interface (G0/1). Suppose that the engineer made the simple mistake of making R4's G0/0 passive instead of G0/1. To show what happens, Example 17-7 changes R4's G0/0 interface to be passive to OSPFv3; note that R4's neighbor relationship to R4 fails almost immediately after the **passive-interface** command is issued.

Example 17-7. Failure of R4's Neighbor Relationship with R1 Due to Passivity

Click here to view code image

```
R4# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R4(config)# ipv6 router ospf 4
R4(config-rtr)# passive-interface gigabitEthernet 0/0
R4(config-rtr)# ^Z
R4#
Jan 17 23:49:56.379: %OSPFv3-5-ADJCHG: Process 4, Nbr 1.1.1.1 on GigabitEthernet0/0
from FULL to DOWN, Neighbor Down: Interface down or detached
```

OSPFv3 Neighbors

As usual, OSPFv3 follows OSPFv2's conventions for how neighbors do their work as well. OSPFv3 uses many of the same protocol message names, neighbor states, and concepts from the processes to form neighbor relationships and exchange the link-state database (LSDB). This next topic looks at some samples of the process, and more important, looks at the number one place to look for OSPF problems: issues that prevent routers from becoming neighbors.

Verifying OSPFv3 Neighbors

Next, Example 17-8 shows some similarities between OSPFv3 and OSPFv2 message names and neighbor states. When reading through the debug output in the example, do not worry about all the detail; instead, focus on the highlighted portions. The highlights list some familiar neighbor states from OSPFv2, like 2-way, exstart, exchange, loading, and full, which is the final desired state in this case.

The example first shows the output from the **debug ipv6 ospf adj** command, which lists messages for OSPFv3 "adjacency" events—that is, what happens when neighbors work through their neighbor states. The end of the example shows R2's **show ipv6 ospf neighbor** command output, which confirms that R2's neighbor state with R3 is the final full state, as mentioned in the debug message. (Note that some debug messages were deleted for the sake of readability.)

Example 17-8. From R2, Watching Changes to Its Neighbor State for R3

Click here to view code image

```
R2# debug ipv6 ospf adj
R2#
Jan 15 14:50:58.098: OSPFv3-2-IPv6 ADJ Gi0/0: Added 3.3.3.3 to nbr list
Jan 15 14:50:58.098: OSPFv3-2-IPv6 ADJ Gi0/0: 2 Way Communication to 3.3.3.3, state 2WAY
Jan 15 14:50:58.098: OSPFv3-2-IPv6 ADJ Gi0/0: DR: 3.3.3.3 (Id) BDR: 2.2.2.2 (Id)
Jan 15 14:50:58.098: OSPFv3-2-IPv6 ADJ Gi0/0: Nbr 3.3.3.3: Prepare dbase exchange
Jan 15 14:50:58.098: OSPFv3-2-IPv6 ADJ Gi0/0: Send DBD to 3.3.3.3 seq 0x2AC5B307 opt 0x0013 flag 0x7 len 28
Jan 15 14:50:58.102: OSPFv3-2-IPv6 ADJ Gi0/0: Rcv DBD from 3.3.3.3 seq 0xBD091ED opt 0x0013 flag 0x7 len 28 mtu
1500 state EXSTART
Jan 15 14:50:58.102: OSPFv3-2-IPv6 ADJ Gi0/0: NBR Negotiation Done. We are the SLAVE
Jan 15 14:50:58.102: OSPFv3-2-IPv6 ADJ Gi0/0: Nbr 3.3.3.3: Summary list built, size 14
Jan 15 14:50:58.106: OSPFv3-2-IPv6 ADJ Gi0/0: Rcv DBD from 3.3.3.3 seq 0xBD091EE opt 0x0013 flag 0x1 len 308
mtu 1500 state EXCHANGE
Jan 15 14:50:58.106: OSPFv3-2-IPv6 ADJ Gi0/0: Exchange Done with 3.3.3.3
Jan 15 14:50:58.106: OSPFv3-2-IPv6 ADJ Gi0/0: Synchronized with 3.3.3.3, state FULL
Jan 15 14:50:58.106: %OSPFv3-5-ADJCHG: Process 2, Nbr 3.3.3.3 on GigabitEthernet0/0
from LOADING to FULL, Loading Done

R2# show ipv6 ospf neighbors

Neighbor ID Pri State Dead Time Interface ID Interface
1.1.1.1 0 FULL/ - 00:00:38 6 Serial0/0/1
3.3.3.3 1 FULL/DR 00:00:37 3 GigabitEthernet0/0
```

Just like with OSPFv2, working OSPFv3 neighbors will stabilize either in a full state or a 2-way state. Most neighbors reach a full state, meaning that they fully exchanged their LSDBs directly to/from each other. However, for any OSPF network type that uses a designated router (DR), only the neighbor relationships with the DR and backup DR (BDR) reach a full state. Neighbor relationships between routers that are neither DR nor BDR—DROther routers—will stabilize to a 2-way state.

Troubleshooting OSPFv3 Neighbors

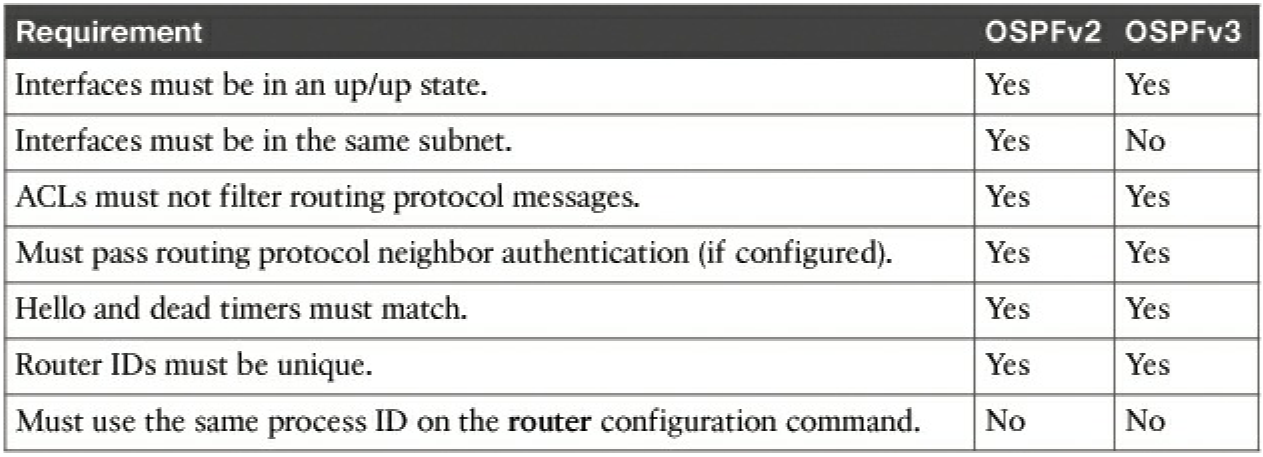
Any time it appears that OSPFv3 fails to learn routes that it should be learning, look at the expected OSPFv3 neighbor relationships. Then, if you find a relationship that does not exist, or exists but does not reach the expected state (full or 2-way), you can focus on the various reasons why a neighbor relationship would not work.

> **Note**
>
> As with OSPFv2, a neighbor in a full state is said to be *fully adjacent*, whereas two DROther neighbors that stabilize to a 2-way state are said to simply be *adjacent*.

Troubleshooting OSPF neighbor relationships requires that you remember many details about items that could prevent two routers from becoming neighbors at all. Thankfully, OSPFv3 uses the same list as OSPFv2, with one noticeable difference: OSPFv3 does not require the neighbors to be in the same subnet. Table 17-2 lists the items to consider when troubleshooting OSPF neighbor relationships.

Key Topic

Table 17-2. Neighbor Requirements for OSPFv2 and OSPFv3

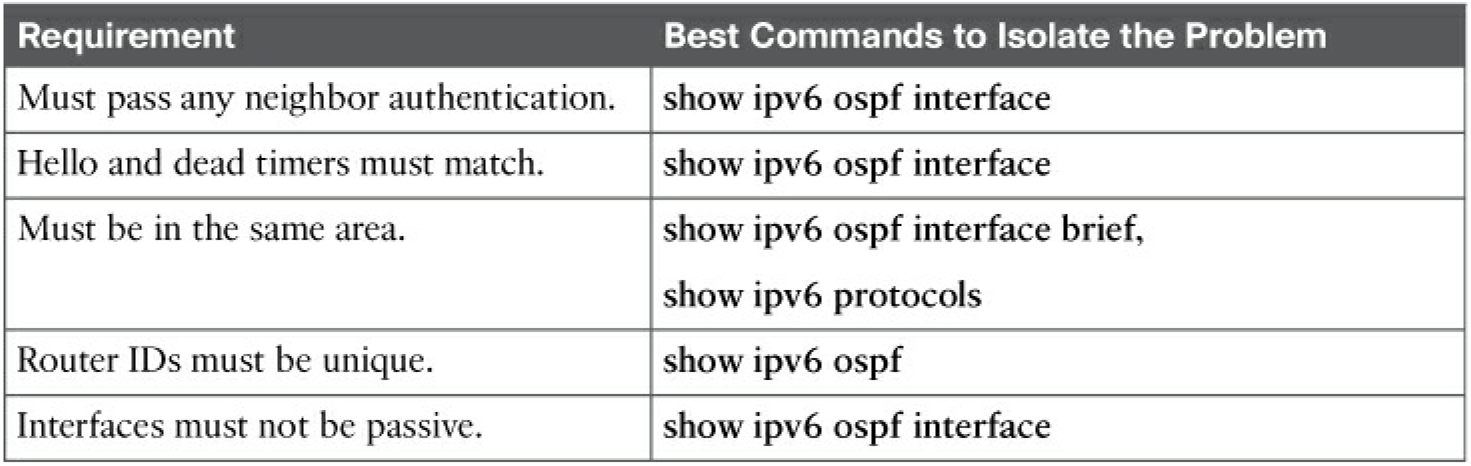


Requirement	OSPFv2	OSPFv3
Interfaces must be in an up/up state.	Yes	Yes
Interfaces must be in the same subnet.	Yes	No
ACLs must not filter routing protocol messages.	Yes	Yes
Must pass routing protocol neighbor authentication (if configured).	Yes	Yes
Hello and dead timers must match.	Yes	Yes
Router IDs must be unique.	Yes	Yes
Must use the same process ID on the **router** configuration command.	No	No

When troubleshooting a problem, use the commands listed in Table 17-3 to quickly find the right piece of information to determine if that particular setting is preventing two routers from becoming neighbors.

Key Topic

Table 17-3. OSPF Neighbor Requirements and the Best show**/**debug **Commands**



Requirement	Best Commands to Isolate the Problem
Must pass any neighbor authentication.	show ipv6 ospf interface
Hello and dead timers must match.	show ipv6 ospf interface
Must be in the same area.	show ipv6 ospf interface brief, show ipv6 protocols
Router IDs must be unique.	show ipv6 ospf
Interfaces must not be passive.	show ipv6 ospf interface

This section shows a couple of examples of problems that can exist between OSPFv3 neighbors. First, Example 17-9 shows a configuration in which a router (R4) purposefully sets its RID to the same number as a neighbor (R1, RID 1.1.1.1). Reading down in the example's highlighted portions, the following happens:

1. R4 changes its RID to 1.1.1.1.
2. R4 clears its OSPFv3 process, so that it starts using the new 1.1.1.1 RID.
3. R4 lists a syslog message stating the neighbor relationship went down (due to the **clear** command).
4. R4 lists a syslog message stating why R4 will not now become neighbors with R1 (1.1.1.1).

Example 17-9. Results from R4 Changing Its RID to the Same 1.1.1.1 Value as R1

Click here to view code image

```
R4# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R4(config)# ipv6 router ospf 4
R4(config-rtr)# router-id 1.1.1.1
% OSPFv3: Reload or use "clear ipv6 ospf process" command, for this to take effect
R4(config-rtr)# ^Z

R4# clear ipv6 ospf process
Reset ALL OSPF processes? [no]: yes
R4#
Jan 17 23:22:03.211: %OSPFv3-5-ADJCHG: Process 4, Nbr 1.1.1.1 on GigabitEthernet0/0
from FULL to DOWN, Neighbor Down: Interface down or detached
R4#
Jan 17 23:22:05.635: %OSPFv3-4-DUP_RTRID_NBR: OSPF detected duplicate router-id
1.1.1.1 from FE80::604:5FF:FE05:707 on interface GigabitEthernet0/0
R4#
R4# show ipv6 ospf neighbor
R4#
```

At the end of the example, the **show ipv6 ospf neighbor** command confirms that R4 now has no OSPFv3 neighbors. (Note that these examples still use the same network design shown in Figures 17-1 and 17-2, with the router normally having one neighbor, namely R1.) The duplicate RID now prevents R4 and R1 from becoming neighbors, so R4's **show ipv6 ospf neighbor** command lists no lines of output at all.

The next example (Example 17-10) mimics the OSPFv2 Hello and dead timer mismatch issue shown back in Chapter 11, "Troubleshooting IPv4 Routing Protocols," in the section "Finding OSPF Hello and Dead Timer Mismatches." Again based on Figures 17-1 and 17-2, R3's Hello and dead timers are 10 and 40, respectively, which are the default values on Ethernet interfaces. Before gathering this output, R2's configuration of the **ipv6 ospf hello-interval 5** interface subcommand on R2's G0/0 interface changed R2's Hello and dead timers to 5 and 20, respectively. (This command sets the Hello timer, and IOS then sets the dead timer to four times the Hello timer.)

Example 17-10. R3 Missing from R2's OSPFv3 Neighbor Table

Click here to view code image

```
R2# show ipv6 ospf neighbor

Neighbor ID Pri State Dead Time Interface ID Interface
1.1.1.1 0 FULL/ - 00:00:35 6 Serial0/0/1
```

```
R2# show ipv6 ospf interface g0/0
GigabitEthernet0/0 is up, line protocol is up
Link Local Address FE80::FF:FE00:2, Interface ID 3
Area 23, Process ID 2, Instance ID 0, Router ID 2.2.2.2
Network Type BROADCAST, Cost: 1
Transmit Delay is 1 sec, State DR, Priority 1
Designated Router (ID) 2.2.2.2, local address FE80::FF:FE00:2
No backup designated router on this network
Timer intervals configured, Hello 5, Dead 20, Wait 20, Retransmit 5
```

The two commands listed in Example 17-10 confirm that R2 and R3 are not longer neighbors over the LAN. However, just as with the similar OSPFv2 example back in Chapter 11, the router does not issue a syslog message telling us the root cause of the problem. With **show** commands, the only way to find this particular mismatch is to look at both routers with the **show ipv6 ospf interface** command; Example 17-10 shows an example from R2, listing its new values of 5 and 20 for the Hello and dead timers.

OSPFv3 LSDB and LSAs

Once OSPFv3 routers become neighbors, they proceed to exchange their LSDBs over that subnet. In most cases, the two routers exchange their LSDBs directly, and when finished, each router lists its neighbor as having reached a full state. Once in a full state, the two routers should have the same link-state advertisements (LSA) for that area.

This section takes a brief look at the LSDB and the LSAs in an area, which once again look similar to the LSDB and LSAs used for OSPFv2. Then this section looks at one rare configuration issue that allows two routers to become OSPFv3 neighbors for a short time, while causing the topology exchange process to fail.

Verifying OSPFv3 LSAs

OSPFv3 uses similar concepts, with slightly different naming for the equivalent of OSPFv2's Type 1, 2, and 3 LSAs. As explained back in Chapter 8, OSPFv2 uses the Type 1 router LSA and Type 2 network LSA to define the topology inside an area. The Type 3 summary LSA then describes for one area a subnet that exists in some other area—an interarea subnet, if you will.

For the configuration options shown for OSPFv2 in this book, only these three types of LSAs are needed in the OSPFv2 LSDB.

OSPFv3 keeps those same three LSA concepts, renaming the summary LSA. The following list summarizes these three key OSPFv3 LSA types and the reasons why OSPFv3 routers create each:

Key Topic

- One router LSA (Type 1 LSA) for each router in the area (including ABRs attached to the area)
- One network LSA (Type 2 LSA) for each network that has a DR plus one neighbor of the DR
- One interarea prefix (Type 3 LSA) LSA for each IPv6 prefix (subnet) that exists in a different area

For example, in area 4 in the sample network used throughout this chapter, two routers exist: internal router R4 and ABR R1. So, the area 4 LSDB will have a router LSA for each router. One network exists in this area for which a DR will be used (the Ethernet WAN between R1 and R4). R1 and R4 will become neighbors, as well, so one network LSA will be created for that network. Finally, ABR R1 will know about five different IPv6 prefixes that exist outside area 4, so ABR R1 should create and flood five interarea prefix LSAs into area 4. Figure 17-6 shows the conceptual model of these LSAs for area 4.

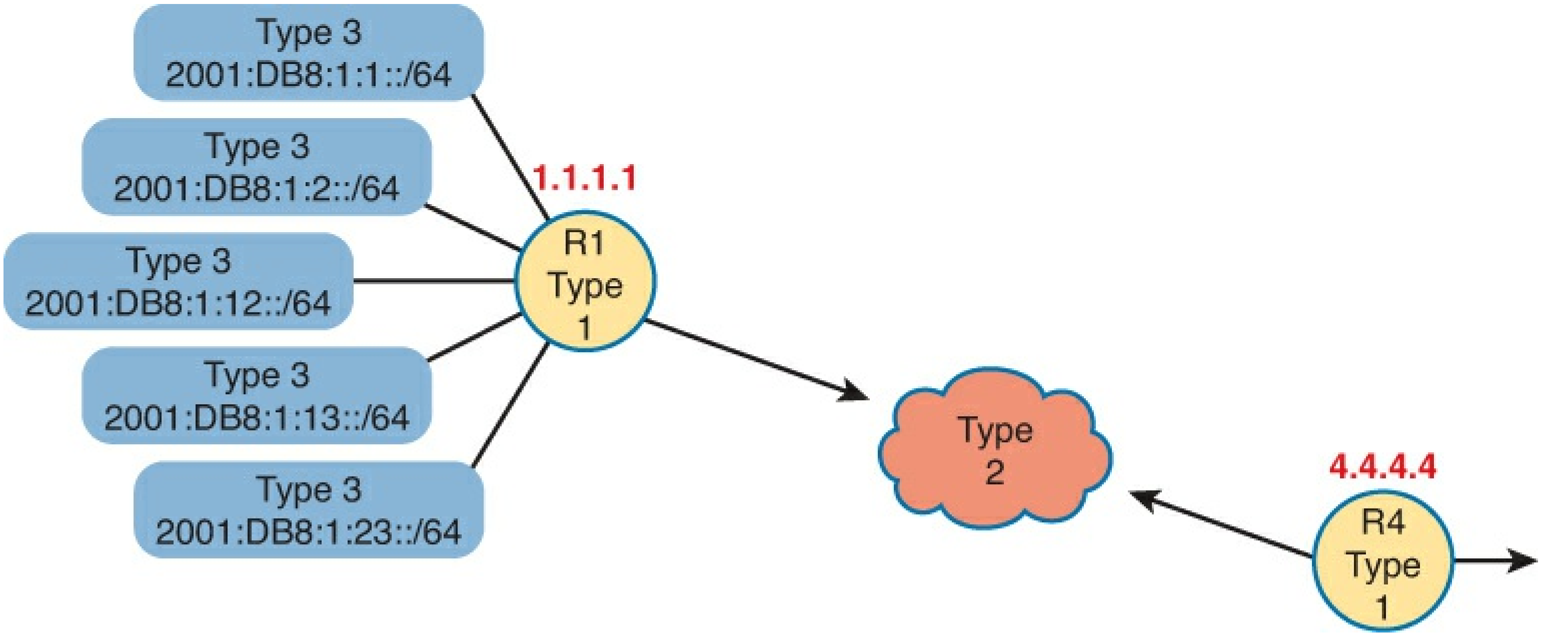


Figure 17-6. Type 1, 2, and 3 LSAs That Should Exist in Area 4

Beyond this basic LSA structure, OSPFv3 does make several changes to LSAs compared to OSPFv2. The details inside these LSAs change, and OSPFv3 adds several new LSA types not seen in OSPFv2. However, these details are beyond the scope of this book.

> **Note**
>
> For perspective, at the time this book was published in 2013, the then-current *CCNP ROUTE Official Cert Guide* did not cover the differences in LSAs between OSPFv2 and OSPFv3 either.

To see the LSAs of Figure 17-6 in an actual router, Example 17-11 lists the beginning of the area 4 LSDB as it exists in router R4. The example highlights the headings and the IPv6 prefixes of the interarea prefix LSAs. Note that the output indeed shows two router LSAs, one line for the single network LSA and five lines with the interarea prefixes.

Example 17-11. LSDB Content in Area 4, as Viewed from R4

Click here to view code image

```
R4# show ipv6 ospf database

OSPFv3 Router with ID (4.4.4.4) (Process ID 4)

Router Link States (Area 4)

ADV Router Age Seq# Fragment ID Link count Bits
1.1.1.1 258 0x80000072 0 1 B
4.4.4.4 257 0x80000003 0 1 None

Net Link States (Area 4)

ADV Router Age Seq# Link ID Rtr count
4.4.4.4 257 0x80000001 4 2

Inter Area Prefix Link States (Area 4)

ADV Router Age Seq# Prefix
1.1.1.1 878 0x80000069 2001:DB8:1:1::/64
1.1.1.1 878 0x80000068 2001:DB8:1:2::/64
1.1.1.1 364 0x8000000A 2001:DB8:1:13::/64
1.1.1.1 364 0x8000000A 2001:DB8:1:23::/64
1.1.1.1 364 0x8000000A 2001:DB8:1:12::/64
! Lines omitted for brevity
```

Troubleshooting OSPFv3 LSAs

Database exchange normally works correctly if two routers indeed become neighbors. That is, most of the problems for both OSPFv2 and OSPFv3 show up before the topology database exchange process happens. By way of review, two routers must first pass all the neighbor compatibility checks and reach 2-way state before attempting to exchange the topology databases. So, the configuration problems that prevent routers from becoming neighbors have been passed before the database exchange is attempted.

One misconfiguration problem actually allows two routers to become neighbors, attempt to do database exchange, and then fail after trying for a few minutes. The problem: mismatched IPv4 or IPv6 maximum transmission unit (MTU) sizes.

First, consider the idea of the MTU size, ignoring OSPF for a moment. The MTU size is a setting for a Layer 3 protocol, both IPv4 and IPv6. For now, consider only IPv6. The IPv6 MTU size of an interface defines the maximum size IPv6 packet that the router can forward out an interface. The same idea works for IPv4, with the IPv4 MTU.

> **Note**
>
> In IPv4, routers can fragment IPv4 packets into smaller packets if a packet exceeds an interface MTU. In IPv6, hosts can detect the smallest MTU over an entire end-to-end route and avoid sending packets that exceed any MTU.

Most router interfaces default to an IPv4 and IPv6 MTU of 1500 bytes. You can change these values with the **ip mtu** *size* and **ipv6 mtu** *size* interface subcommands for IPv4 and IPv6, respectively.

Now think back to OSPFv3 and the fact that two routers can become neighbors and then fail to exchange their LSDBs because of unequal MTU settings. Specifically, the neighbors learn of each other with Hellos, reach a 2-way state, and reach exstart state at the beginning of the database exchange process. However, database exchange fails because of the MTU mismatch, and the neighbor relationship fails to a down state.

Example 17-12 shows an example of that specific failure on R4. The example first changes R4's G0/0 IPv6 MTU to 1400, and then resets the OSPFv3 process.

Example 17-12. Failure to Exchange the LSDB Because of a Mismatched IPv6 MTU

Click here to view code image

```
R4# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R4(config)# interface gigabitethernet0/0
R4(config-if)# ipv6 mtu 1400
R4(config-if)# ^Z
R4#
R4# clear ipv6 ospf 4 process
Reset OSPF process? [no]: yes
R4#
Jan 17 23:53:24.439: %OSPFv3-5-ADJCHG: Process 4, Nbr 1.1.1.1 on GigabitEthernet0/0 from FULL to DOWN, Neighbor
Down: Interface down or detached

R4# show ipv6 ospf neighbor

Neighbor ID Pri State Dead Time Interface ID Interface
1.1.1.1 1 EXSTART/DR 00:00:37 4 GigabitEthernet0/0

Jan 17 23:55:29.063: %OSPFv3-5-ADJCHG: Process 4, Nbr 1.1.1.1 on GigabitEthernet0/0
from EXSTART to DOWN, Neighbor Down: Too many retransmits
R4# show ipv6 ospf neighbor

Neighbor ID Pri State Dead Time Interface ID Interface
1.1.1.1 1 DOWN/DROTHER - 4 GigabitEthernet0/0
```

The last command in the example may be the key to noticing this particular problem on the exam. The two routers (R1 and R4) know of each other because the OSPF Hello messages have no problems at all. So, the **show ipv6 ospf neighbor** command on each router still lists the other router, as shown in R4's output that mentions neighbor R1 (1.1.1.1). However, after a while, the neighbor relationship fails to a down state. So, when you see a neighbor in what looks like a permanent down state, check the IPv6 MTU on both sides (with the **show ipv6 interface** command).

OSPFv3 Metrics and IPv6 Routes

At the end of all this noise about LSAs, database exchange, matching parameters for neighbors, and so on, the routers need to choose the best IPv6 routes to use. This final topic of the chapter reviews a few verification steps for how OSPFv3 calculates the metrics, and then looks at some more troubleshooting tips—this time about what to do with missing or suboptimal IPv6 routes.

Verifying OSPFv3 Interface Cost and Metrics

The SPF algorithm looks for all possible routes, or paths, from the local router to each and every subnet. When redundant paths exist between the local router and some remote subnet, the SPF algorithm has to pick the better route, based on the lower metric of the end-to-end route, as shown in the example shown earlier in Figure 17-3.

When OSPFv3 adds a route to the IPv6 routing table, the metric for the route is the second of the two numbers in brackets for the route. (The first number in brackets is the administrative distance (AD); the IPv6 routing protocols use the same default AD values as their IPv4 counterparts.)

For example, first focus on the two metric 65 routes R1 learns for subnet 2001:DB8:1:23::/64, as shown in Figure 17-7. For the route through R2, R1 adds its S0/0/0 cost of 64 to R2's G0/0 cost of 1, for a total cost of 65. R1 calculates a metric 65 route through R3, as well. With a default setting of **maximum-paths 4**, R1 placed both routes into the routing table. (One route uses R2 as the next hop, and one uses R3.)

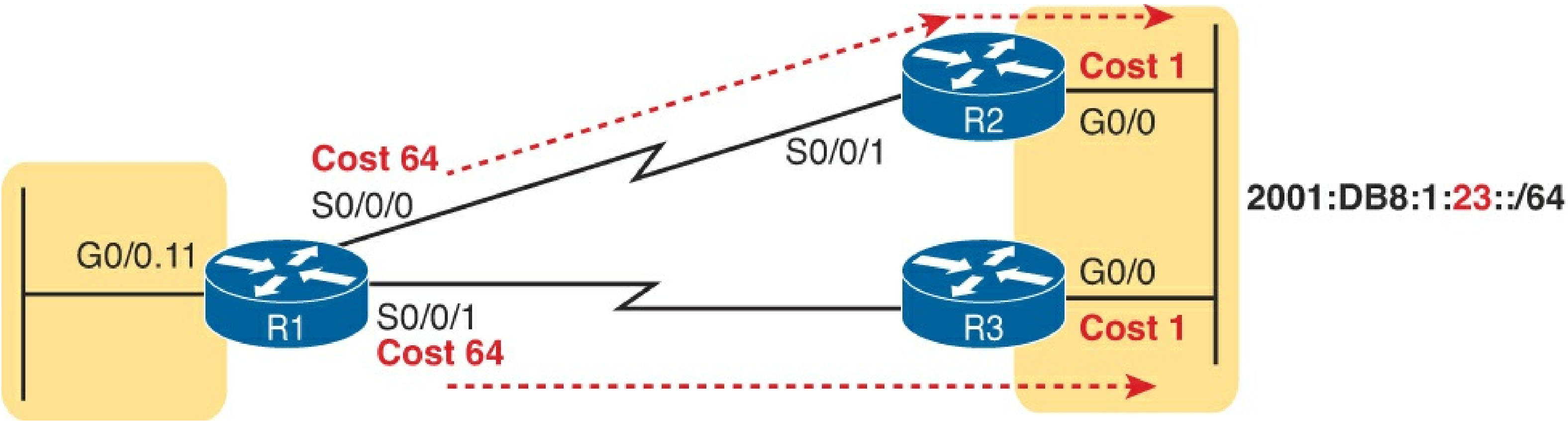


Figure 17-7. Two Equal-Metric Routes from R1 to 2001:DB8:1:23::/64

Example 17-13 shows these two routes for subnet 2001:DB8:1:23::/64, as highlighted in the output of the **show ipv6 route ospf** command on router R1. As usual, the OSPF-learned routes list a next-hop link-local address. To see which route refers to R2, and which refers to R3, check the outgoing interfaces and compare them to Figure 17-7.

Example 17-13. OSPFv3 Routes on R1

Click here to view code image

```
R1# show ipv6 route ospf
! Legend omitted for brevity

O 2001:DB8:1:4::/64 [110/1]
via GigabitEthernet0/1, directly connected
O 2001:DB8:1:23::/64 [110/65]
via FE80::FF:FE00:3, Serial0/0/1
via FE80::FF:FE00:2, Serial0/0/0
```

To see an example of what happens when a router has multiple routes but chooses one route because it has a better metric, next look at R2's OSPF-learned IPv6 routes in Example 17-14, focusing on the router to the subnet to the left side of router R1 (subnet 2001:DB8:1:1::/64):

- R2 has two possible routes (per the topology diagram 17-1) to reach subnet 2001:DB8:1:1::/64: one through R1, out R2's S0/0/1 interface; and one through R3, out R2's G0/0 interface.
- R2 only placed one of these two routes into the IPv6 routing table: a route with metric 65, out R2's S0/0/1 interface. This cost is based on R2's default S0/0/1 cost of 64, plus R1's G0/0.11 cost of 1.
- R2 decided the route through R3 was worse because the cost was the sum of R2's G0/0 cost (1), R3's S0/0/0 cost (64), and R1's G0/0.11 cost (1), for a total of 66.

Figure 17-8 shows the interface costs for these two competing routes. Note that the drawing omits parts of the network as shown earlier in Figure 17-1.

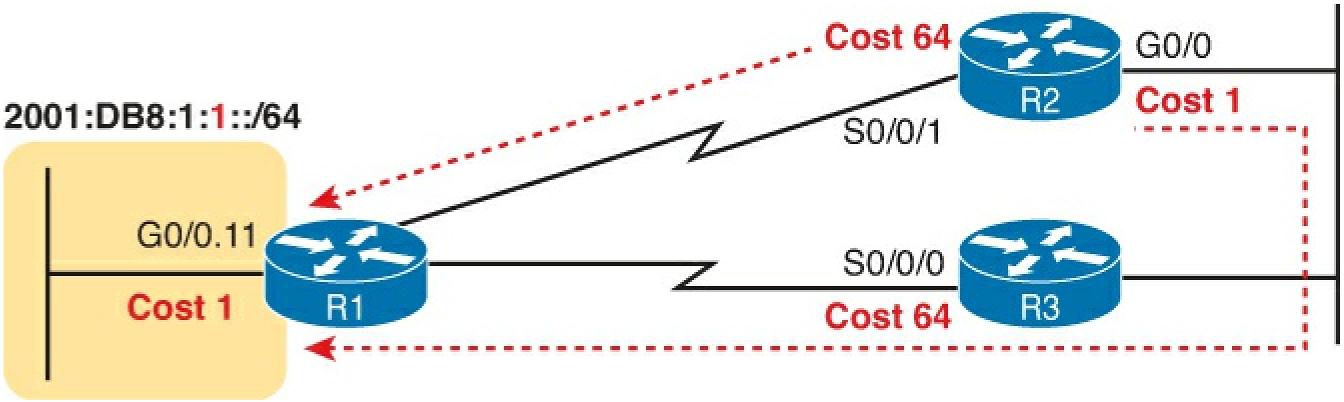


Figure 17-8. R2's Competing Routes to Reach Subnet 1

Example 17-14. OSPFv3 Routes on R1

Click here to view code image

```
R2# show ipv6 route ospf
! Legend omitted for brevity
OI 2001:DB8:1:1::/64 [110/65]
```

```
via FE80::FF:FE00:1, Serial0/0/1
OI 2001:DB8:1:2::/64 [110/65]
via FE80::FF:FE00:1, Serial0/0/1
OI 2001:DB8:1:4::/64 [110/65]
via FE80::FF:FE00:1, Serial0/0/1
O 2001:DB8:1:13::/64 [110/65]
via FE80::FF:FE00:3, GigabitEthernet0/0
OI 2001:DB8:1:14::/64 [110/65]
via FE80::FF:FE00:1, Serial0/0/1
```

Also, note that the code letters on the left of most of these routes on R2 are *OI*. The *O* identifies the route as being learned by OSPF, and the *I* identifies the route as an interarea route. For instance, the highlighted entry lists prefix/subnet 1 (2001:DB8:1:1::/64), which sits in area 0, and R2 is in area 23. So, R2's route to this subnet is an interarea route. (Earlier, Example 17-13 showed several intra-area OSPF routes, each with code letter *O* instead of *OI*.)

OSPFv3 displays the settings for OSPFv3 interface cost with commands similar to OSPFv2. For the default calculations, the **show ipv6 ospf** command lists the reference bandwidth, and the **show interfaces** command lists the interface bandwidth. Example 17-15 shows the current OSPFv3 interface costs on R1 with the **show ipv6 ospf interface brief** command.

Example 17-15. Finding a Router's OSPFv3 Interface Costs

Click here to view code image

```
R1# show ipv6 ospf interface brief
Interface PID Area Intf ID Cost State Nbrs F/C
Gi0/0.12 1 0 16 1 DR 0/0
Gi0/0.11 1 0 17 1 DR 0/0
Gi0/1 1 4 4 1 BDR 1/1
Se0/0/0 1 23 6 64 P2P 1/1
Se0/0/1 1 23 7 64 P2P 1/1
```

Troubleshooting IPv6 Routes Added by OSPFv3

If a problem appears to be related to IPv6 routing, the problems can be put into two broad categories. First, a router may be missing a route for some prefix, so the router discards the packet, and pings fail. Second, a router may have a working route, but it appears to take a suboptimal route to the destination. (Chapter 16, "Troubleshooting IPv6 Routing," in the "Traceroute Shows Some Hops, But Fails" section, discusses yet a third category in which a routing loop occurs.)

For example, in Figure 17-9, router R1 has two possible routes to reach subnet 33, an IPv6 subnet off router R3. The top route appears to be the better route, at least in terms of the number of routers between R1 and subnet 33. If R1 has no routes at all to subnet 33, you might look for one type of root cause; but if R1 uses the lower route through five routers, you might look for a different root cause.

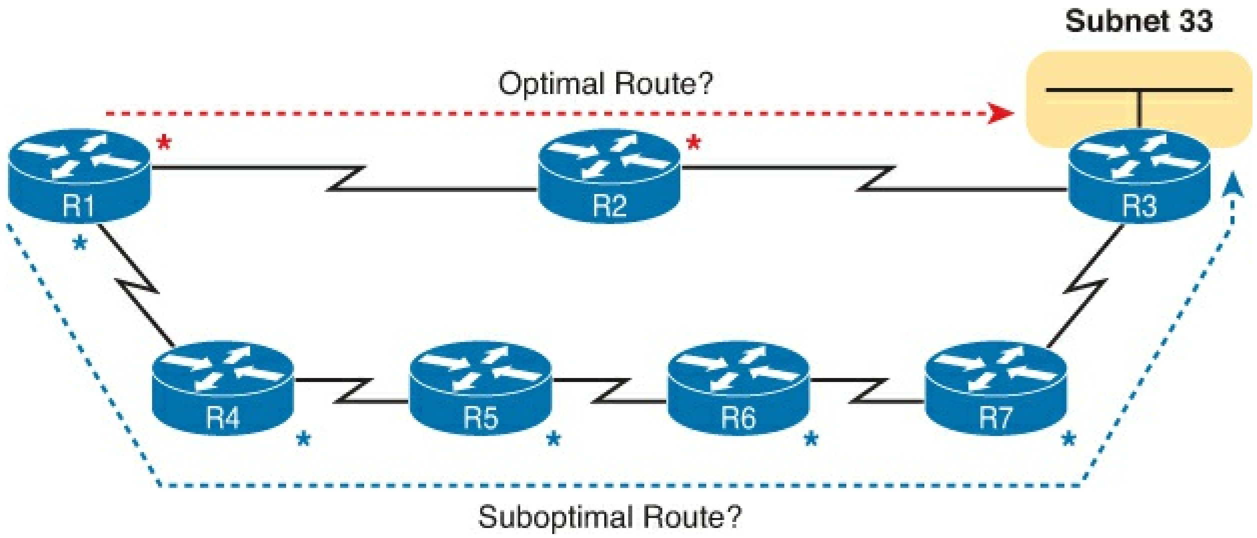


Figure 17-9. Competing Long and Short Routes from R1 to Subnet 33

When a router simply has no route to a given subnet—for instance, if R1 has no route at all for subnet 33—do the following:

Key Topic

Step 1. Check the routers with interfaces directly connected to that IPv6 prefix. A router must have OSPFv3 enabled on that interface before OSPFv3 will advertise about the subnet.

Step 2. Check OSPFv3 neighbor relationships for all routers between the local router and the routers with an interface connected to IPv6 prefix X.

For instance, in Figure 17-9, if router R3 did not have an **ipv6 ospf** *process-id* **area** *area-id* command on its LAN interface, all seven routers could have working neighbor relationships, but R3 still would not advertise about subnet 33.

If a router has a route, but it appears to be the wrong (suboptimal) route, take these steps:

Step 1. Check for broken neighbor relationships over what should be the optimal path from the local router and prefix Y.

Step 2. Check the OSPFv3 cost settings on the interfaces in the optimal path.

For instance, in Figure 17-9, suppose that R1 indeed has one route for subnet 33, pointing over the lower route, with R4 as the next-hop router. The root cause of that choice could be the following:

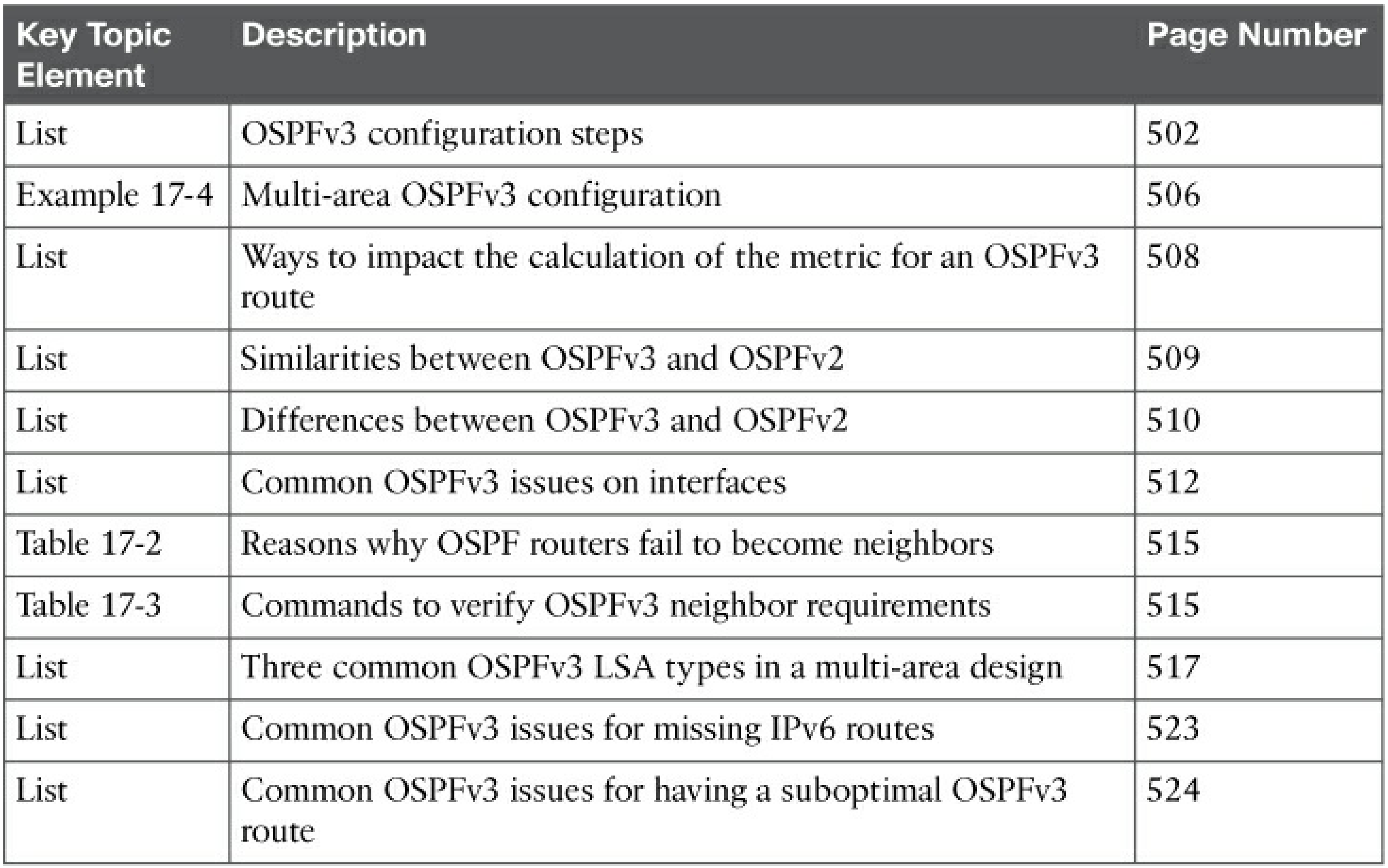
- The R2-R3 neighbor relationship is not working.
- The sum of the costs for the top route is larger (worse) than the sum of the costs for the lower route. (Note that the figure shows an asterisk beside each interface whose cost is part of the calculation.)

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 17-4 lists these key topics and where each is discussed.

Table 17-4. Key Topics for Chapter 17



Key Topic Element	Description	Page Number
List	OSPFv3 configuration steps	502
Example 17-4	Multi-area OSPFv3 configuration	506
List	Ways to impact the calculation of the metric for an OSPFv3 route	508
List	Similarities between OSPFv3 and OSPFv2	509
List	Differences between OSPFv3 and OSPFv2	510
List	Common OSPFv3 issues on interfaces	512
Table 17-2	Reasons why OSPF routers fail to become neighbors	515
Table 17-3	Commands to verify OSPFv3 neighbor requirements	515
List	Three common OSPFv3 LSA types in a multi-area design	517
List	Common OSPFv3 issues for missing IPv6 routes	523
List	Common OSPFv3 issues for having a suboptimal OSPFv3 route	524

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix D, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix E, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Definitions of Key Terms

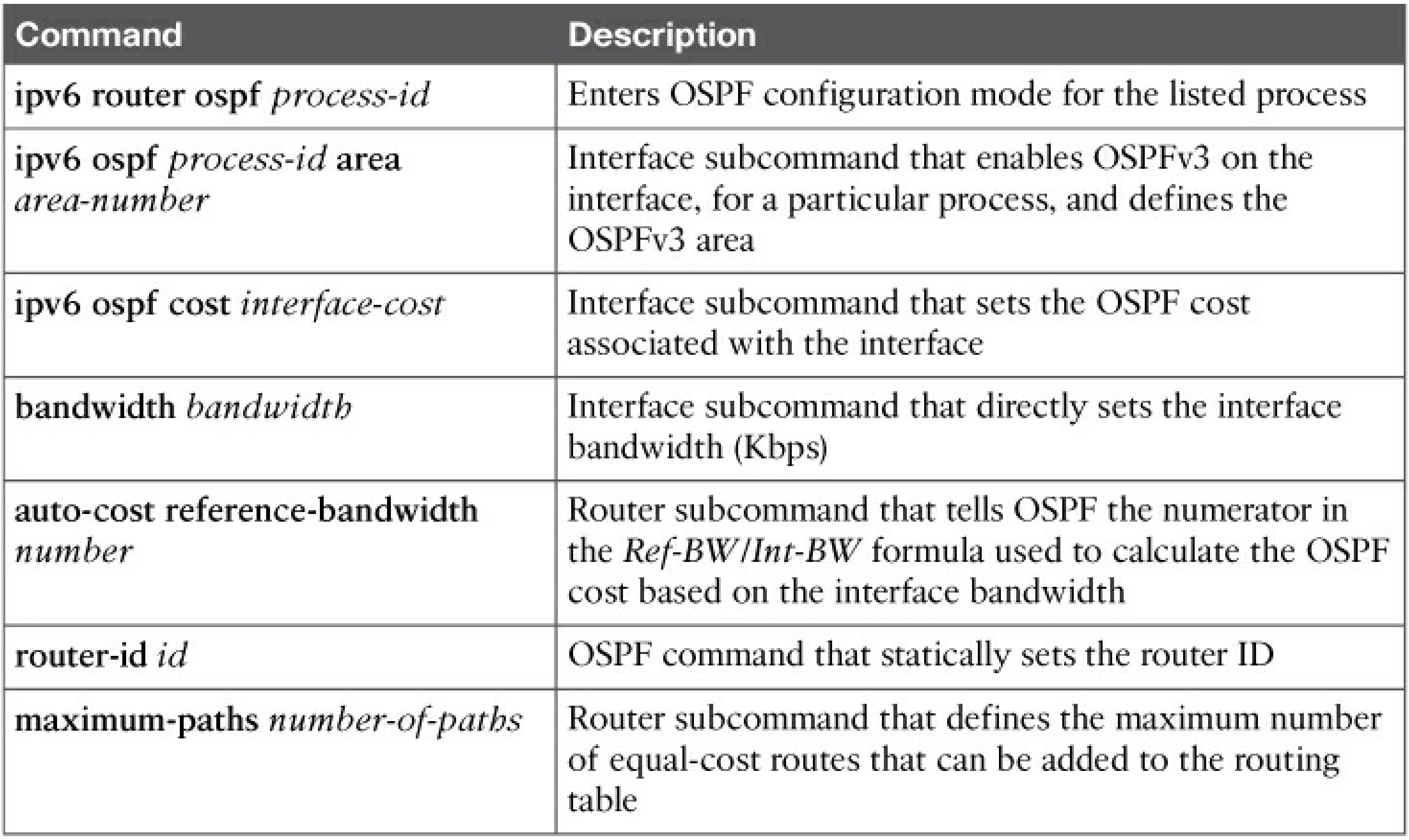
After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22 directs you in how to use these terms for late-stage preparation for the exam.

multi-area
area border router
internal router
backbone area
router ID
full
2-way
router LSA
network LSA
interarea prefix LSA
maximum transmission unit (MTU)

Command Reference to Check Your Memory

Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table, read the descriptions on the right side, and see if you remember the command.

Table 17-5. Chapter 17 Configuration Command Reference



Command	Description
ipv6 router ospf *process-id*	Enters OSPF configuration mode for the listed process
ipv6 ospf *process-id* **area** *area-number*	Interface subcommand that enables OSPFv3 on the interface, for a particular process, and defines the OSPFv3 area
ipv6 ospf cost *interface-cost*	Interface subcommand that sets the OSPF cost associated with the interface
bandwidth *bandwidth*	Interface subcommand that directly sets the interface bandwidth (Kbps)
auto-cost reference-bandwidth *number*	Router subcommand that tells OSPF the numerator in the *Ref-BW/Int-BW* formula used to calculate the OSPF cost based on the interface bandwidth
router-id *id*	OSPF command that statically sets the router ID
maximum-paths *number-of-paths*	Router subcommand that defines the maximum number of equal-cost routes that can be added to the routing table

Table 17-6. Chapter 17 show **Command Reference**

Command	Description
show ipv6 ospf	Lists information about the OSPF process running on the router, including the OSPF router ID, areas to which the router connects and the number of interfaces in each area.
show ipv6 ospf interface brief	Lists the interfaces on which the OSPF protocol is enabled (based on the **network** commands), including passive interfaces.
show ipv6 ospf interface *type number*	Lists a long section of settings, status, and counters for OSPF operation on all interfaces, or on the listed interface, including the Hello and dead timers.
show ipv6 protocols	Lists all means through which a router can learn or build IPv6 routes, including the interfaces on which each routing protocol is enabled.
show ipv6 ospf neighbor [*type number*]	Lists brief output about neighbors, identified by neighbor router ID, including current state, with one line per neighbor; optionally, limit the output to neighbors on the listed interface.
show ipv6 ospf neighbor *neighbor-ID*	Lists the same output as the **show ip ospf neighbor detail** command, but only for the listed neighbor (by neighbor router ID).
show ipv6 ospf database	Lists a summary of the LSAs in the database, with one line of output per LSA. It is organized by LSA type (first Type 1, then Type 2, and so on).
show ipv6 route	Lists all IPv4 routes.
show ipv6 route ospf	Lists routes in the routing table learned by OSPF.
show ipv6 route *prefix/length*	Shows a detailed description of the route for the listed subnet/mask.

Chapter 18. Implementing EIGRP for IPv6

This chapter covers the following exam topics:

IP Routing Technologies

- Configure and verify EIGRP (single AS)
  - Feasible distance *feasible successors* administrative distance
  - Feasibility condition
  - Metric composition
  - Router ID
  - Path selection
  - Load balancing
    - Equal
    - Unequal
  - Passive interface
- Differentiate methods of routing and routing protocols
  - metric
  - next hop

Troubleshooting

- Troubleshoot and Resolve EIGRP problems
  - Neighbor adjacencies
  - AS number
  - Load balancing
  - Split horizon

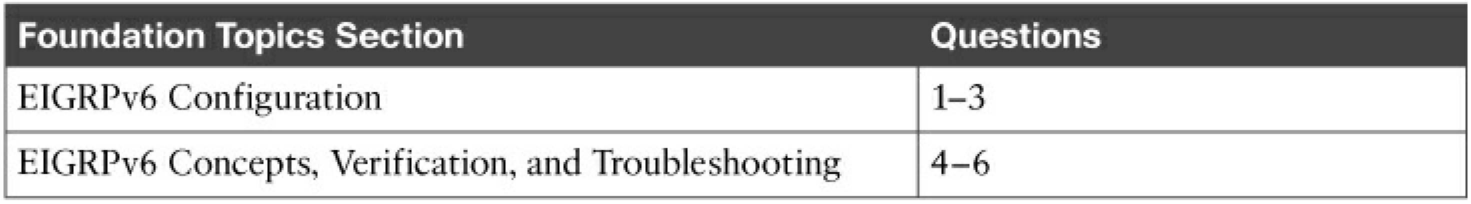
When creating Enhanced Interior Gateway Routing Protocol (EIGRP) for IPv6 (EIGRPv6), Cisco made the new EIGRPv6 as much like EIGRP for IPv4 (EIGRPv4) as possible. How close are they? Incredibly close, even closer than the IPv4 and IPv6 versions of the Open Shortest Path First (OSPF) Protocol. With EIGRP, the only noticeable difference is the configuration, which enables EIGRPv6 directly on the interfaces and, of course, the use of IPv6 addresses and prefixes. However, the old and new EIGRP protocols are practically twins when it comes to the concepts, **show** commands, and troubleshooting steps.

This chapter follows the same sequence as the preceding chapter. The first major section shows the EIGRPv6 configuration options, comparing those steps with EIGRPv4. The second major section shows how to verify EIGRPv6 while giving some troubleshooting tips.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 18-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
EIGRPv6 Configuration	1–3
EIGRPv6 Concepts, Verification, and Troubleshooting	4–6

1. An enterprise uses a dual-stack model of deployment for IPv4 and IPv6, using EIGRP as the routing protocol for both. Router R1 has IPv4 and IPv6 addresses on its G0/0 and S0/0/0 interfaces only, with EIGRPv4 and EIGRPv6 enabled on both interfaces. Which of the following answers is a valid way to configure R1 so that it enables EIGRPv6 on the exact same interfaces as EIGRPv4 in this case?
   - **a.** Adding the **dual-stack all-interfaces** router subcommand for EIGRPv6
   - **b.** Adding the **dual-stack** interface subcommand to interfaces G0/0 and S0/0/0
   - **c.** Adding the **ipv6 eigrp** *asn* interface subcommand to interfaces G0/0 and S0/0/0
   - **d.** Adding the **dual-stack all-interfaces** router subcommand for EIGRPv4
2. Which of the following configuration settings do not have a separate IPv4/EIGRPv4 and IPv6/EIGRPv6 setting, instead using one setting that both EIGRPv4 and EIGRPv6 both use?
   - **a.** Interface bandwidth
   - **b.** Hello timer

   c. Variance

   d. Maximum paths

3. An enterprise uses a dual-stack model of deployment for IPv4 and IPv6, using EIGRP as the routing protocol for both. Router R1 has IPv4 and IPv6 addresses on its G0/0 and S0/0/0 interfaces only, with EIGRPv4 and EIGRPv6 enabled on both interfaces and the router ID explicitly set for both protocols. Comparing the EIGRPv4 and EIGRPv6 configuration, which of the following statements are true?

   a. The EIGRPv6 configuration uses the **router eigrp** *asn* global command

   b. Both protocols use the **router-id** *router-id* router subcommand

   c. Both protocols use the **network** *network-number* router subcommand

   d. The EIGRPv6 configuration uses the **ipv6 eigrp** *asn* interface subcommand

4. Three redundant IPv6 routes exist on R1 to reach IPv6 subnet 9 (2009:9:9:9::/64), a subnet connected to router R9's G0/0 interface. R1's current successor route uses R2 as the next hop, with feasible successor routes through routers R3 and R4. Then, another engineer makes changes to the configuration in the network, resulting in R1 having no routes to reach subnet 9. Which of the answers lists one configuration that would result in R1 having no routes at all to subnet 9?

   a. Make R9's G0/0 interface passive.

   b. Change R2's EIGRP ASN to some other number, but otherwise keep the same configuration.

   c. Change the Hello timers on all of R1's interfaces from 5 to 4.

   d. Change R1's EIGRP ASN to some other number, but otherwise keep the same configuration.

5. R1 and R2 are routers that connect to the same VLAN. Which of the answers lists an item that can prevent the two routers from becoming EIGRPv6 neighbors? (Choose two answers.)

   a. Mismatched Hello timers

   b. Mismatched ASNs

   c. IPv6 addresses in different subnets

   d. Using the same router ID

   e. One passive router interface (used on this link)

6. The output of the **show ipv6 eigrp neighbors** command from R2 lists one neighbor. Which of the following answers is correct about the meaning of the output of the command in this example?

Click here to view code image

```
R2# show ipv6 eigrp neighbors
EIGRP-IPv6 Neighbors for AS(1)
H Address Interface Hold Uptime SRTT RTO Q Seq
(sec) (ms) Cnt Num
0 Link-local address: Gi0/0 11 06:46:11 1 100 0 30
FE80::FF:FE22.2222
```

   a. The neighbor's link-local address on their common link must be FE80::FF:FE22:2222.

   b. The neighbor's EIGRPv6 router ID must be FE80::FF:FE22:2222.

   c. R2's link-local address on their common link must be FE80::FF:FE22:2222.

   d. R2's EIGRPv6 router ID must be FE80::FF:FE22:2222.

Answers to the "Do I Know This Already?" quiz:

1 C 2 A 3 D 4 D 5 B and E 6 A

Foundation Topics

EIGRPv6 Configuration

EIGRPv6 behaves much like its IPv4 counterpart, EIGRP. Once enabled on all routers in an internetwork, the routers exchange EIGRP messages. Those messages allow the routers to discover neighbors, form neighbor relationships, advertise subnets along with their metric components, and calculate metrics for competing routes using the same old calculation. EIGRPv6 also uses the same successor and feasible successor (FS) logic, and DUAL processing when no FS exists.

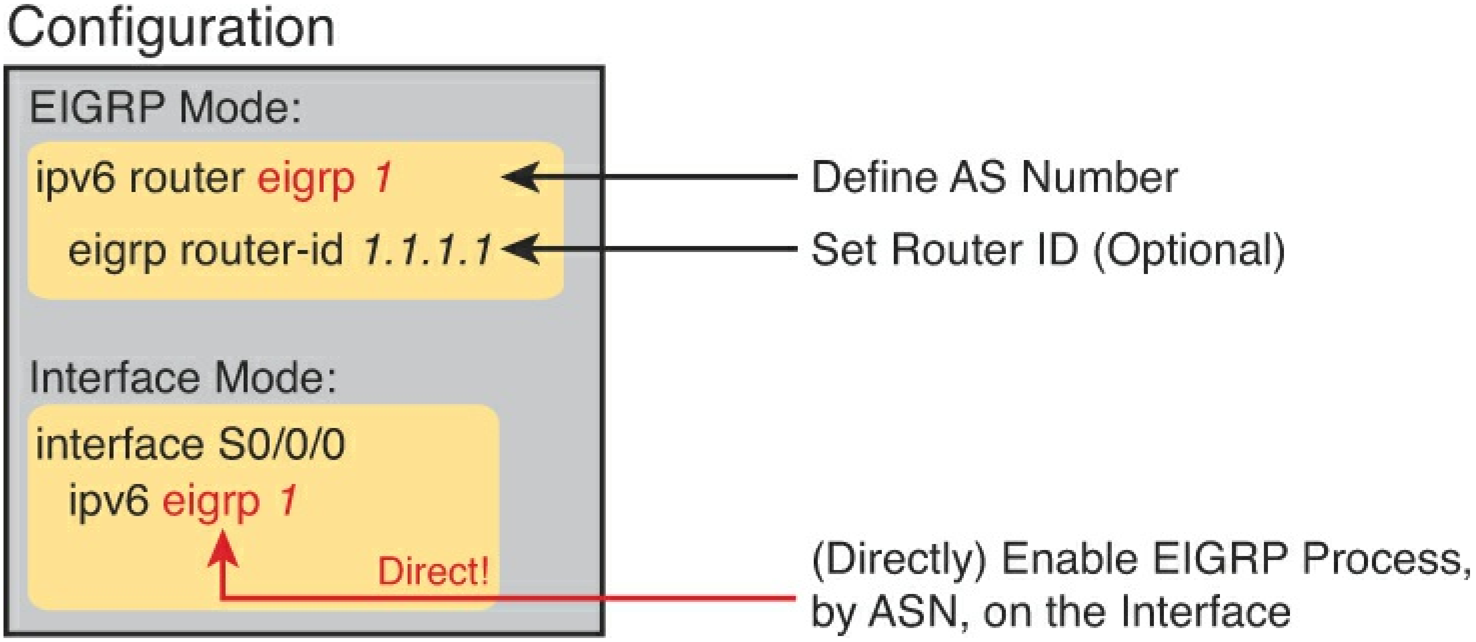
Differences do exist, of course, with the most obvious being that EIGRPv6 advertises IPv6 prefixes, not IPv4 subnets. The messages flow in IPv6 packets, many going to IPv6 multicast address FF02::A. But most of the big ideas mirror EIGRP for IPv4.

EIGRPv6 configuration requires the usual steps for all routing protocols. The EIGRPv6 routing protocol process must be created, and then the protocol must then be enabled on various interfaces. The rest of the EIGRPv6 configuration is optional, to change some default setting, with changes to what happens between neighbors, what metric is calculated, and so on.

This first section first works through both the most common EIGRPv6 configuration commands, followed by a look at the various other commands used to change some small feature.

EIGRPv6 Configuration Basics

EIGRPv6 configuration works much like OSPFv3. That is, the commands create the EIGRPv6 process in one part of the configuration, with interface subcommands enabling the routing protocol on the interface. Figure 18-1 shows the fundamentals of this core configuration for IPv6.



```
ipv6 router eigrp 1
  eigrp router-id 1.1.1.1

interface S0/0/0
  ipv6 eigrp 1
```

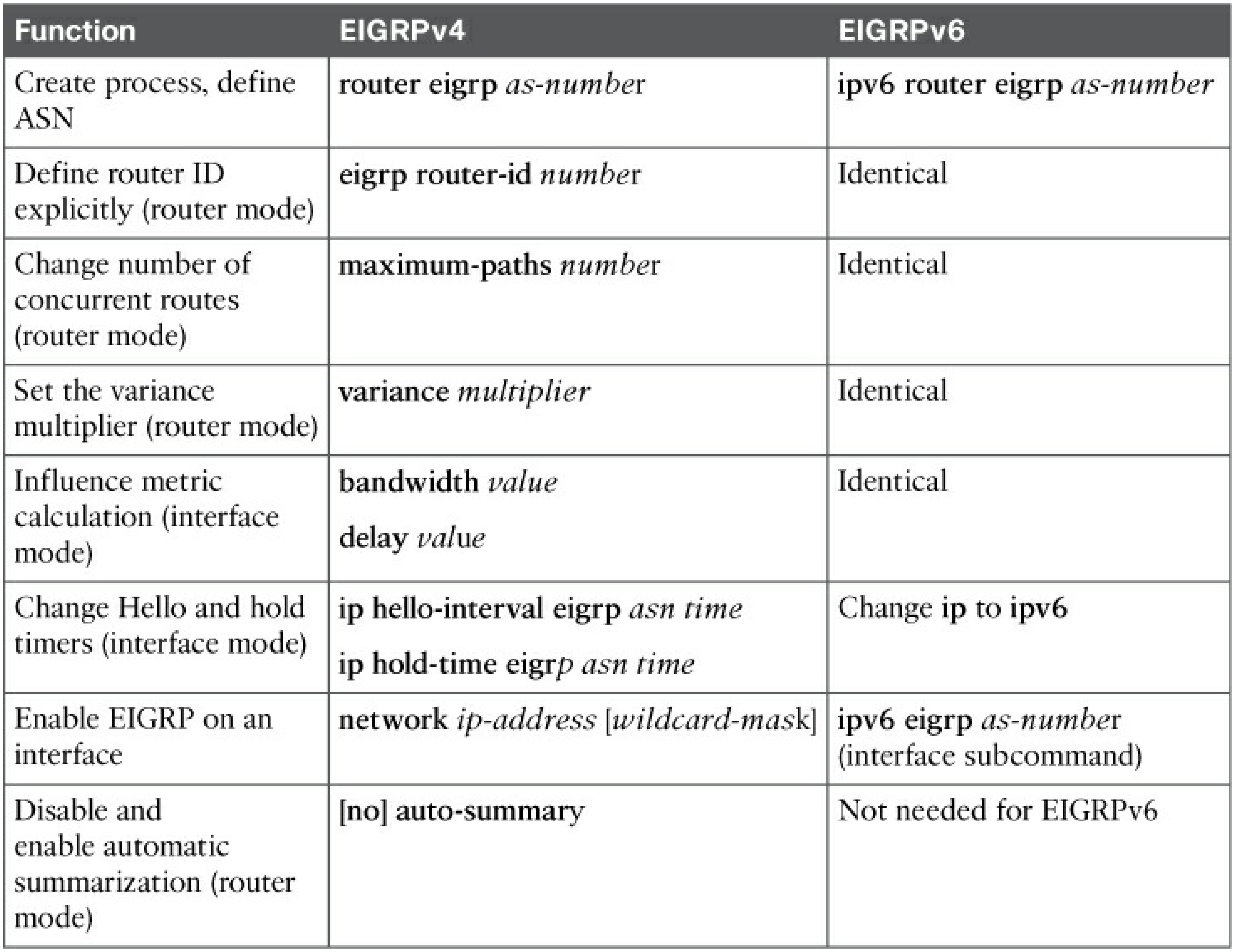
Figure 18-1. Fundamentals of EIGRPv6 Configuration

If you remember EIGRPv4 configuration, you will quickly see one key difference between the configuration in Figure 18-1 and what you know about EIGRPv4. The example in the figure does not use any EIGRP **network** commands at all because EIGRPv6 does not even support the **network** command. Instead, it uses the **ipv6 eigrp asn** interface subcommand. This process works like the OSPFv3 configuration from the preceding chapter, just with a slightly different command for EIGRPv6.

The rest of the EIGRPv6 configuration commands work either exactly like the EIGRPv4 commands or very similarly to them. To show the similarities, Table 18-2 lists the EIGRPv4 configuration options introduced in Chapter 10, "Implementing EIGRP for IPv4," making comparisons to the similar configuration options in EIGRPv6.

Key Topic

Table 18-2. Comparison of EIGRPv4 and EIGRPv6 Configuration Commands



Function	EIGRPv4	EIGRPv6
Create process, define ASN	**router eigrp** *as-numbe*r	**ipv6 router eigrp** *as-number*
Define router ID explicitly (router mode)	**eigrp router-id** *numbe*r	Identical
Change number of concurrent routes (router mode)	**maximum-paths** *numbe*r	Identical
Set the variance multiplier (router mode)	**variance** *multiplier*	Identical
Influence metric calculation (interface mode)	**bandwidth** *value* **delay** *val*ue	Identical
Change Hello and hold timers (interface mode)	**ip hello-interval eigrp** *asn time* **ip hold-time eigr***p asn time*	Change **ip** to **ipv6**
Enable EIGRP on an interface	**network** *ip-address* [*wildcard-mas*k]	**ipv6 eigrp** *as-numbe*r (interface subcommand)
Disable and enable automatic summarization (router mode)	**[no] auto-summary**	Not needed for EIGRPv6

EIGRPv6 Configuration Example

To show EIGRPv6 configuration in context, the next several pages show an example using the internetwork from Figure 18-2. The figure shows the IPv6 subnets. It also shows the last quartet of each router's interface IPv6 address as ::X, where X is the router number, to make it more obvious as to which router uses which address.

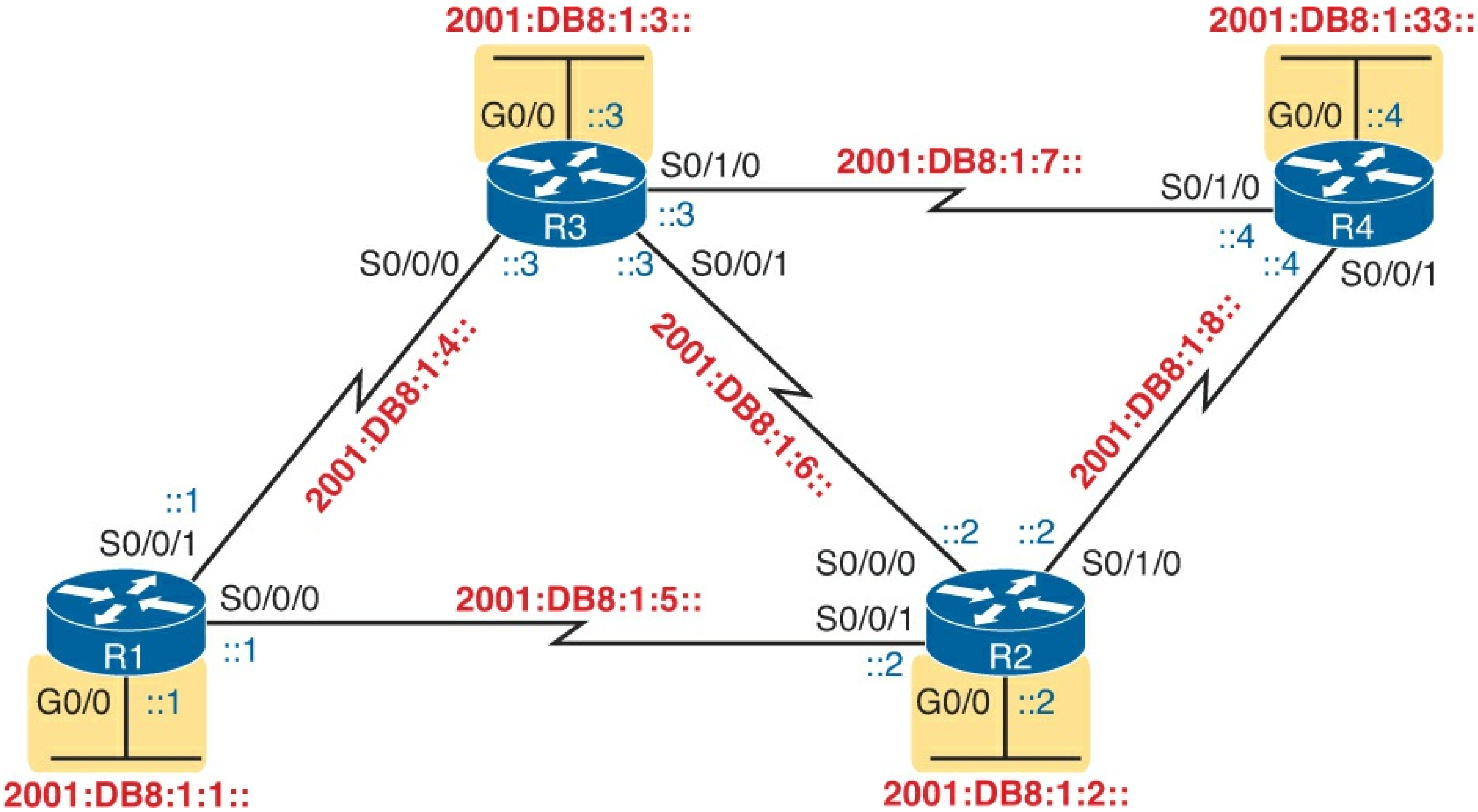

2001:DB8:1:3::
G0/0
::3
2001:DB8:1:33::
G0/0
::4
S0/1/0
2001:DB8:1:7::
S0/1/0
R3
::3
R4
::4
S0/0/0
::3
::3
S0/0/1
::4
S0/0/1
2001:DB8:1:4::
2001:DB8:1:6::
2001:DB8:1:8::
::1
S0/0/1
::2
::2
S0/0/0
S0/1/0
S0/0/0
2001:DB8:1:5::
S0/0/1
R1
::1
::2
R2
G0/0
::1
G0/0
::2
2001:DB8:1:1::
2001:DB8:1:2::

Figure 18-2. The Internetwork for an Example Multi-Area EIGRPv6 Configuration

Note that Figure 18-2 mimics Figure 10-3, used in several EIGRPv4 examples in Chapter 10. Figure 18-2 uses the exact same interface types and numbers and router names. In fact, it uses a similar subnet numbering pattern. For instance, think of the four LAN-based IPv6 subnets as subnets 1, 2, 3, and 33, based on the last quartet values. Those same subnets in the examples in Chapter 10, based on the third octet of the IPv4 subnet numbers, are also 1, 2, 3, and 33, respectively.

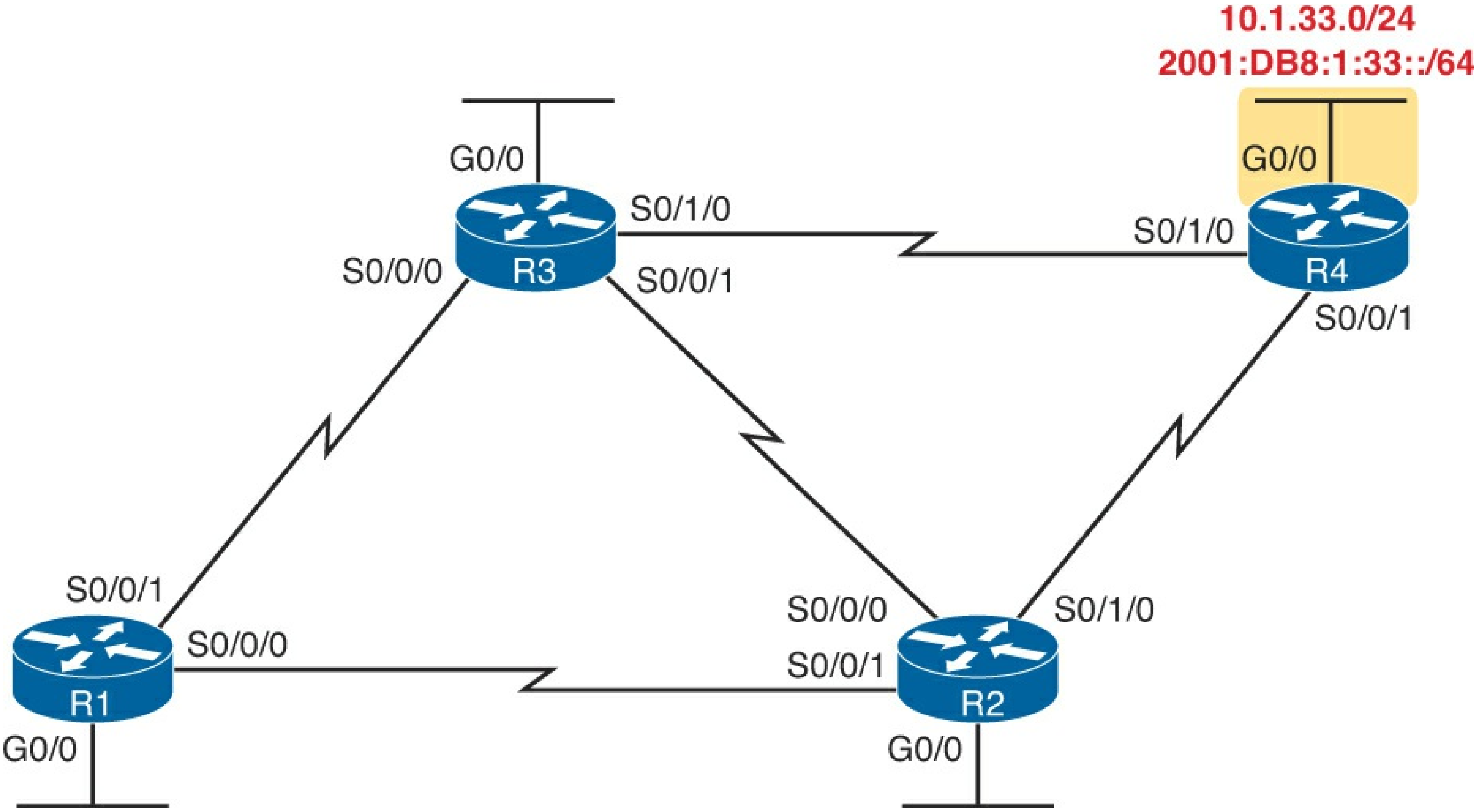

10.1.33.0/24
2001:DB8:1:33::/64
G0/0
G0/0
S0/1/0
S0/1/0
S0/0/0
R3
S0/0/1
R4
S0/0/1
S0/0/1
S0/0/0
S0/1/0
S0/0/0
S0/0/1
R1
R2
G0/0
G0/0

Figure 18-3. Same Location off R4 for IPv4 Subnet 33 and IPv6 Subnet 33

Why does it matter that the internetwork used for this chapter mirrors the one used in Chapter 10? Not only are the EIGRP configuration commands similar but also the **show** command output. The **show** commands in this chapter, by using the exact same network topology, list almost the exact same output for EIGRPv6 as they did for EIGRPv4.

For this specific example, Example 18-1 begins by listing the additional IPv6 configuration required on R1 to make it a dual-stack router, including EIGRPv6 configuration. The highlighted lines are the EIGRPv6-specific configuration commands, while the rest of the configuration adds IPv6 routing and addressing.

Example 18-1. IPv6 and EIGRPv6 Configuration on Router R1

Click here to view code image

```
ipv6 unicast-routing
!
ipv6 router eigrp 1
eigrp router-id 1.1.1.1
!
interface GigabitEthernet0/0
ipv6 address 2001:db8:1:1::1/64
ipv6 eigrp 1
!
interface serial 0/0/0
description link to R2
ipv6 address 2001:db8:1:5::1/64
ipv6 eigrp 1
!
interface serial 0/0/1
description link to R3
ipv6 address 2001:db8:1:4::1/64
ipv6 eigrp 1
```

With this first example, take a few moments to review the configuration thoroughly. All the routers need to use the same EIGRPv6 autonomous system number (ASN), as configured on the **ipv6 router eigrp** *asn* global command. Just after this command, the R1 explicitly sets its EIGRP router ID (RID) using the **eigrp router-id** command. Note that EIGRPv6 also uses a 32-bit RID, as does OSPFv3, with the same exact rules for how a router picks the value.

The rest of the configuration simply enables EIGRPv6 on each interface by referring to the correct EIGRPv6 process, by ASN, using the **ipv6 eigrp** *asn* interface subcommand.

Example 18-2 shows the configuration on a second router (R2). Note that it also uses ASN 1 because it must match the ASN used by router R1. Otherwise, these two routers will not become neighbors. Also, note that R2 sets its RID to 2.2.2.2.

Example 18-2. EIGRPv6 Configuration on R2

Click here to view code image

```
ipv6 unicast-routing
!
ipv6 router eigrp 1
eigrp router-id 2.2.2.2
!
interface GigabitEthernet0/0
ipv6 address 2001:db8:1:2::2/64
ipv6 eigrp 1
!
interface serial 0/0/0
description link to R3
ipv6 address 2001:db8:1:6::2/64
ipv6 eigrp 1
!
interface serial 0/0/1
description link to R1
ipv6 address 2001:db8:1:5::2/64
ipv6 eigrp 1
!
interface serial 0/1/0
description link to R4
ipv6 address 2001:db8:1:8::2/64
ipv6 eigrp 1
```

Note

IOS allows the EIGRPv6 routing process to be disabled, and then reenabled, using the **shutdown** and **no shutdown** commands in EIGRP configuration mode. Examples 18-1 and 18-2 do not include the **no shutdown** command because the IOS version used on the routers for this book (15.2(M)) defaults to an enabled (**no shutdown**) state. However, note that earlier IOS versions defaulted to a disabled state, requiring the configuration of a **no shutdown** command in EIGRP configuration mode before EIGRPv6 would work.

Other EIGRPv6 Configuration Settings

The example shows the basics for EIGRPv6 configuration. The next few pages discuss a few configuration options in comparison to EIGRPv4.

Setting Bandwidth and Delay to Influence EIGRPv6 Route Selection

By default, EIGRPv6 uses the exact same settings as EIGRPv4 when calculating the metrics for each route. And to be extra clear, the settings are not similar or simply using the same command syntax. EIGRPv6 uses the exact same settings as EIGRPv4, specifically the interface bandwidth and delay settings, as configured with the **bandwidth** and **delay** interface subcommands. A change to these values impacts both EIGRPv4's calculation of metrics as well as EIGRPv6's calculation.

EIGRPv6 also uses the exact same formula as EIGRPv4 to calculate the metric for a route. As a result, in some conditions, the EIGRPv4 metric for a route to an IPv4 subnet will be the same metric as the EIGRPv6 route from the same router to IPv6 subnet in the same location.

For instance, in Figure 18-3, all the routers are dual-stack routers, with EIGRPv4 and EIGRPv6 enabled on all the interfaces in the design. Subnet 10.1.33.0/24 has been noted in the upper right, in the same location as IPv6 subnet 33 (2001:DB8:1:33::/64). R1's EIGRPv4 and EIGRPv6 processes will calculate the same exact metric for these routes based on the same collection of interface bandwidth and delay settings.

Example 18-3 shows the IPv4 and IPv6 routes on R1 for the subnets shown in Figure 18-3. Note the highlighted metrics in all cases are 2,684,416.

Example 18-3. Identical Metrics for IPv4 and IPv6 Routes with EIGRPv4 and EIGRPv6

Click here to view code image

```
R1# show ip route | section 10.1.33.0
D 10.1.33.0/24 [90/2684416] via 10.1.5.2, 00:02:23, Serial0/0/0
[90/2684416] via 10.1.4.3, 00:02:23, Serial0/0/1

R1# show ipv6 route | section 2001:DB8:1:33::/64
D 2001:DB8:1:33::/64 [90/2684416]
via FE80::FF:FE00:3, Serial0/0/1
via FE80::FF:FE00:2, Serial0/0/0
```

Note that both commands list two equal-cost routes on R1, for subnet 33, but the format of the output differs a little. The format of the **show ip route** command puts the destination subnet on the same first line as the first route's forwarding instructions. The **show ipv6 route** command lists the destination prefix on the first line, with each route's forwarding instructions on the second and third lines, respectively.

EIGRP Load Balancing

EIGRPv6 and EIGRPv4 use the exact same concepts, with the exact same configuration command syntax, for equal-cost and unequal-cost load balancing. However, EIGRPv6 has its own configuration settings, made with the **maximum-paths** and **variance** commands inside EIGRPv6 configuration mode. EIGRPv4 has separate settings, using these same two commands, in EIGRPv4 configuration mode.

For example, imagine that in a dual-stack network, the routers use EIGRPv4 and EIGRPv6. The network engineer would probably choose the same **variance** and **maximum-paths** settings for both routing protocols. However, for the sake of pointing out the differences, imagine the engineer chose different settings, like these:

- **EIGRPv4:** At most 2 routes, with variance 3 for unequal cost routes
- **EIGRPv6:** At most 5 routes, with variance 4 for unequal cost routes

Example 18-4 shows how to make these different settings for these two different routing processes. However, note that the commands happen to use the exact same syntax.

Example 18-4. Setting Load-Balancing Parameters per Routing Process

Click here to view code image

```
R1# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
! First, configure the settings for IPv4
```

```
R1(config)# router eigrp 10
R1(config-router)# maximum-paths 2
R1(config-router)# variance 3
! Next, configure the similar settings for IPv6
R1(config-router)# ipv6 router eigrp 11
R1(config-rtr)# maximum-paths 5
R1(config-rtr)# variance 4
R1(config-rtr)# ^Z
R1#
```

EIGRP Timers

EIGRPv6 and EIGRPv4 use the exact same concepts for the Hello and hold timers as does EIGRPv4. To allow these values to be set differently for each routing process, IOS gives us slightly different syntax on the EIGRPv6 and EIGRPv4 commands, with the EIGRPv6 commands using the keyword **ipv6** rather than **ip**. Otherwise, the EIGRPv6 syntax mirrors the EIGRPv4 version of the commands.

Example 18-5 shows a sample that changes both the EIGRPv4 and EIGRPv6 Hello timer, just to show the different commands side by side. For EIGRPv4, the Hello timer is set to 6 seconds, and for EIGRPv6, it is set to 7 seconds.

Example 18-5. Setting the EIGRPv4 and EIGRPv6 Hello Timers

Click here to view code image

```
R1# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R1(config)# interface gigabitethernet0/1
R1(config-if)# ip hello-interval eigrp 10 6
R1(config-if)# ipv6 hello-interval eigrp 11 7
R1(config-rtr)# ^Z
R1#
```

The choices for the timer values are arbitrary, just to make it clear which command is for each routing protocol. In real networks, these settings will likely have the same values for both EIGRPv4 and EIGRPv6.

EIGRPv6 Concepts, Verification, and Troubleshooting

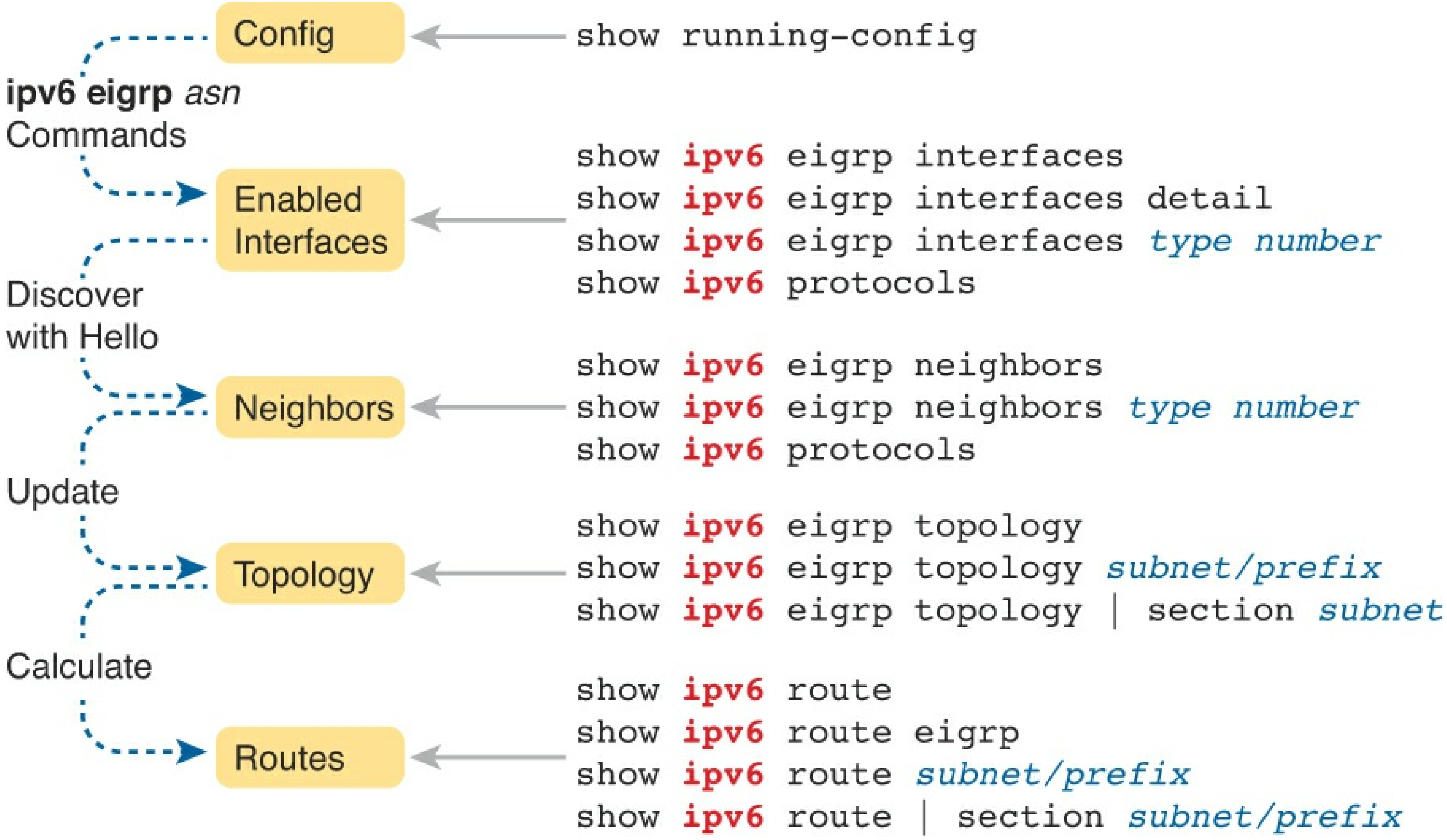
To the depth discussed in this book, EIGRPv4 and EIGRPv6 behave almost identically. Earlier, Table 18-2 listed the configuration commands, side by side, to show the similarities. This second major section of the chapter now looks at EIGRPv6 verification and troubleshooting, with even more similarities between EIGRPv6 as its older cousin EIGRPv4.

So many similarities exist between EIGRPv6 and EIGRPv4 that you should just assume that they work the same, except for a few differences, as noted in the following list:

Key Topic

- EIGRPv6 advertises IPv6 prefixes, whereas EIGRPv4 advertises IPv4 subnets.
- EIGRPv6 **show** commands use a keyword of **ipv6,** in the sample position where EIGRP **show** commands use a keyword of **ip**.
- EIGRPv6 uses the same checklist for choosing whether to become neighbors, except EIGRPv6 routers may become neighbors if they have IPv6 addresses in difference subnets. (EIGRPv4 neighbors must be in the same IPv4 subnet.)
- EIGRPv6 does not have an autosummary concept (while EIGRPv4 does).

As you can see, the list of differences mentioned here is short. The similarities will become clearer through the many examples of **show** command output in the remainder of this chapter. To begin, Figure 18-4 reviews the EIGRPv6 **show** commands discussed in this chapter. Note that all the commands in the figure use the same syntax as the EIGRPv4 equivalent but with **ip** changed to **ipv6**.



```
show running-config

show ipv6 eigrp interfaces
show ipv6 eigrp interfaces detail
show ipv6 eigrp interfaces type number
show ipv6 protocols

show ipv6 eigrp neighbors
show ipv6 eigrp neighbors type number
show ipv6 protocols

show ipv6 eigrp topology
show ipv6 eigrp topology subnet/prefix
show ipv6 eigrp topology | section subnet

show ipv6 route
show ipv6 route eigrp
show ipv6 route subnet/prefix
show ipv6 route | section subnet/prefix
```

Figure 18-4. Reference of EIGRPv6 Verification Commands

Similar to the preceding chapter's flow, this chapter's second major section breaks the discussion down in the same general sequence as EIGRPv6 does when bringing up the EIGRPv6 process. This section first examines EIGRPv6 interfaces, then neighbors, topology, and finally, IPv6 routes.

> **Note**
>
> All the troubleshooting examples in the rest of this chapter use the example configuration from routers R1, R2, R3, and R4, as shown in Figure 18-2.

EIGRPv6 Interfaces

By enabling EIGRPv6 on an interface, the router attempts to do two things:

1. Discover EIGRPv6 neighbors off that interface
2. Advertise about the prefix connected to that interface

To make sure that EIGRPv6 works correctly, an engineer should verify that EIGRPv6 is enabled on the right interfaces. Or, from a troubleshooting perspective, some of the most common problems with EIGRPv6 may be because a router did not enable EIGRPv6 on an interface.

As was the case for EIGRPv4, with EIGRPv6, some commands list all interfaces on which EIGRP is enabled (including passive), some list all EIGRP interfaces but note which are passive, and some simply do not list the passive interfaces. Example 18-6 shows a sample that points out these differences, by first making R1's G0/0 interface passive. It then lists output from the **show ipv6 eigrp interfaces** command, which omits G0/0, and then **show ipv6 protocols** command, which includes G0/0, but noted as a passive interface.

Example 18-6. Verifying OSPFv3 Interfaces and Related Parameters

Click here to view code image

```
R1# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R1(config)# ipv6 router eigrp 1
R1(config-rtr)# passive-interface g0/0
R1(config-rtr)# ^Z
R1#
R1# show ipv6 eigrp interfaces
EIGRP-IPv6 Interfaces for AS(1)
Xmit Queue Mean Pacing Time Multicast Pending
```

```
Interface Peers Un/Reliable SRTT Un/Reliable Flow Timer Routes
Se0/0/0 1 0/0 1 0/15 50 0
Se0/0/1 1 0/0 1 0/15 50 0

R1# show ipv6 protocols
IPv6 Routing Protocol is "connected"
IPv6 Routing Protocol is "eigrp 1"
EIGRP-IPv6 Protocol for AS(1)
Metric weight K1=1, K2=0, K3=1, K4=0, K5=0
NSF-aware route hold timer is 240
Router-ID: 1.1.1.1
Topology : 0 (base)
Active Timer: 3 min
Distance: internal 90 external 170
Maximum path: 16
Maximum hopcount 100
Maximum metric variance 1

Interfaces:
Serial0/0/0
Serial0/0/1
GigabitEthernet0/0 (passive)
Redistribution:
None
IPv6 Routing Protocol is "ND"
```

Note that the **show ipv6 eigrp interfaces** command lists many lines of output per interface. Also, like the **show ipv6 protocols** command, it lists all EIGRP-enabled interfaces, including passive interfaces.

Next, focus for a moment on troubleshooting related to EIGRPv6 interfaces. As with OSPF, most troubleshooting revolves around the neighbor relationships. However, this short list describes two problems that can happen related to the interfaces:

Key Topic

- The omission of an **ipv6 eigrp** *asn* interface subcommand on an interface that has no possible neighbors may go overlooked. This omission does not impact EIGRPv6 neighbors. However, this omission means that EIGRPv6 is not enabled on that interface, and therefore the router will not advertise about that connected subnet. This problem shows up as a missing route.
- Making an interface passive to the EIGRPv6 process, when a potential EIGRPv6 neighbor is connected to that link, prevents the two routers from becoming neighbors. Note that the neighbor relationship fails with just one of the two routers having a passive interface.

For example, consider router R4 in this chapter’s sample network. Its G0/0 interface connects to a LAN, with no other routers. Currently, R4’s configuration includes the **ipv6 eigrp 1** interface subcommand on R4’s G0/0 interface. If instead that command were mistakenly missing (or if it were just removed as an experiment in lab), R4 would not advertise a route for the connected subnet (subnet 33, or 2001:DB8:1:33::/64).

Example 18-7 shows that specific example. To re-create the problem, though, before gathering the output in Example 18-7 on R4, the **no ipv6 eigrp 1** command was issued on R4’s G0/0 interface, disabling EIGRP from that interface. Example 18-7 then shows R1 does not have a route to subnet 33 or EIGRP topology data.

Example 18-7. Missing Route to Subnet 33 on R1

Click here to view code image

```
R1# show ipv6 route 2001:DB8:1:33::
% Route not found

R1# show ipv6 eigrp topology | include 2001:DB8:1:33
R1#
```

EIGRPv6 Neighbors

From one perspective, EIGRP neighbor relationships are simple. When two EIGRPv6 routers sit on the same data link, they discover each other with EIGRPv6 Hello messages. Those Hello messages list some parameters, and the neighbors check the Hello to determine whether the routers should be come neighbors:

- If the parameters match, each router adds the other router to their EIGRPv6 neighbor table, as listed with the **show**

ipv6 eigrp neighbors command.

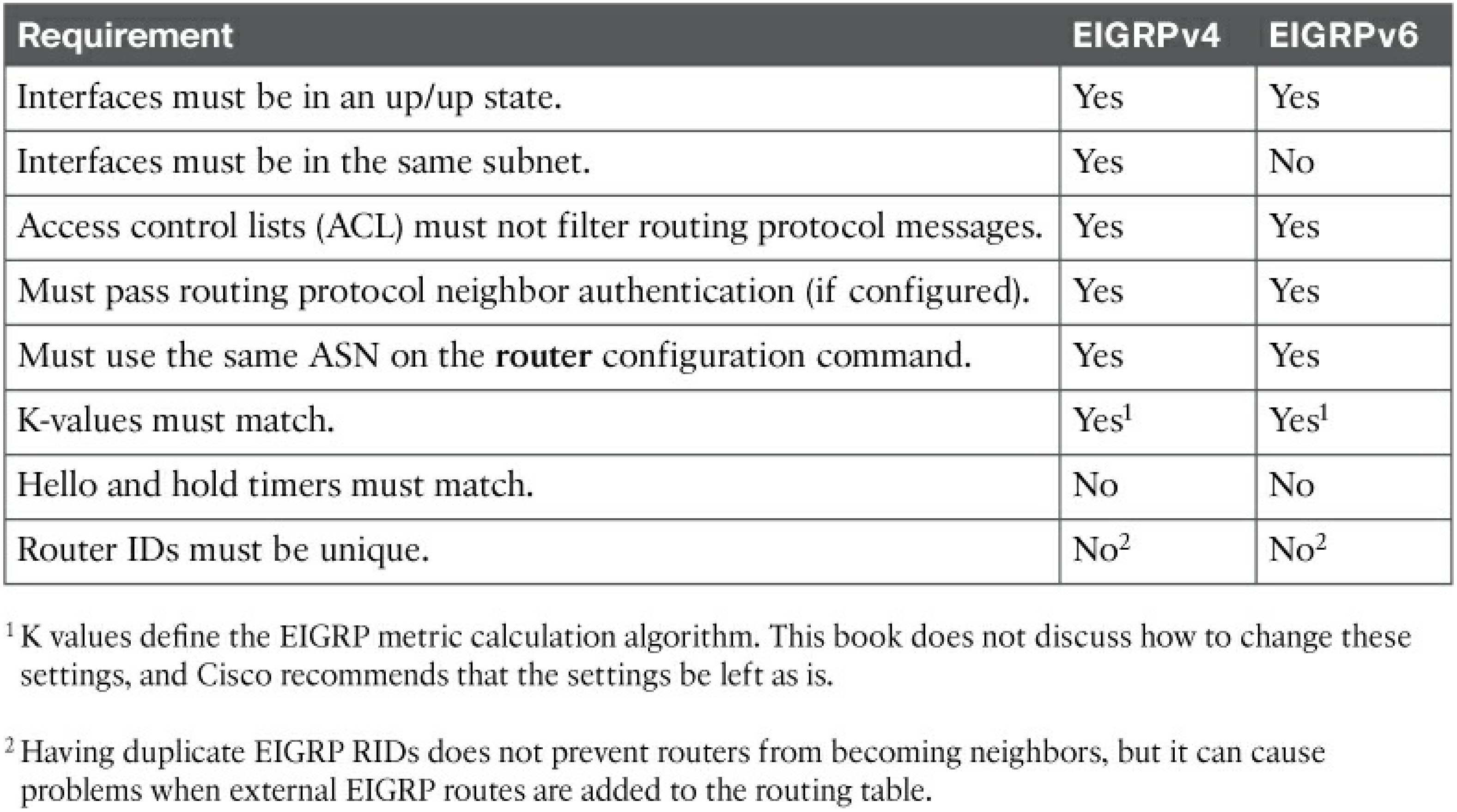
- If the parameters do not match, the routers do not become neighbors, do not add each other to their neighbor tables, and do not list each other in the output of the **show ipv6 eigrp neighbors** command.

From another perspective, troubleshooting EIGRP neighbor relationships means that you have to remember a lot of small details. The neighbors check lists of parameters that must match. At the same time, other problems can prevent the routers from becoming neighbors as well. Thankfully, EIGRPv6 uses the same list as EIGRPv4, with one noticeable difference: EIGRPv6 does not require the neighbors to be in the same subnet.

Table 18-3 lists the items to consider when troubleshooting EIGRP neighbor relationships.

Key Topic

Table 18-3. Neighbor Requirements for EIGRPv4 and EIGRPv6



Requirement	EIGRPv4	EIGRPv6
Interfaces must be in an up/up state.	Yes	Yes
Interfaces must be in the same subnet.	Yes	No
Access control lists (ACL) must not filter routing protocol messages.	Yes	Yes
Must pass routing protocol neighbor authentication (if configured).	Yes	Yes
Must use the same ASN on the **router** configuration command.	Yes	Yes
K-values must match.	Yes[1]	Yes[1]
Hello and hold timers must match.	No	No
Router IDs must be unique.	No[2]	No[2]

[1] K values define the EIGRP metric calculation algorithm. This book does not discuss how to change these settings, and Cisco recommends that the settings be left as is.

[2] Having duplicate EIGRP RIDs does not prevent routers from becoming neighbors, but it can cause problems when external EIGRP routes are added to the routing table.

For instance, in the configuration example in this chapter, all four routers used EIGRPv6 ASN 1. However, suppose that router R2's configuration had mistakenly used ASN 2, while the other three routers correctly used ASN 1. What would happen? R2 would have failed to form a neighbor relationship with any of the other routers.

Many EIGRPv6 **show** commands mention the EIGRPv6 ASN, but the **show ipv6 protocols** command shows the value in a couple of obvious places. Example 18-6, earlier, shows this.

As a troubleshooting strategy for the exam, note that every pair of EIGRPv6 routers on the same link should become neighbors. So, when an exam question appears to point to some IPv6 routing problem, check the routers, count the EIGRP neighbor relationships and make sure all the neighbor relationships exist. If any are missing, start troubleshooting EIGRPv6 neighbor relationships based on Table 18-3.

To examine the neighbors, use the **show ipv6 eigrp neighbors** command. Because of the length of IPv6 addresses, this command lists two lines per neighbor rather than one line (as is the case with the EIGRPv4 version of this command). The output in Example 18-8 shows this command's output from router R2, with highlights in two lines for a single neighbor (R3).

Example 18-8. R2's EIGRPv6 Neighbors

Click here to view code image

```
R2# show ipv6 eigrp neighbors
EIGRP-IPv6 Neighbors for AS(1)
H Address Interface Hold Uptime SRTT RTO Q Seq
(sec) (ms) Cnt Num
2 Link-local address: Se0/1/0 10 06:37:34 104 624 0 13
FE80::D68C:B5FF:FE6B:DB48
```

```
1 Link-local address: Se0/0/0 11 06:37:54 1 100 0 38
FE80::FF:FE00:3
0 Link-local address: Se0/0/1 11 06:46:11 1 100 0 30
FE80::FF:FE00:1
```

Take a moment to focus on the IPv6 address and interface listed in the highlighted two lines. The output, taken from router R2, lists R3's link-local address that sits on the other end of R2's S0/0/0 interface. The listed S0/0/0 interface is R2's interface. In summary, the details list the local router's interface and the neighbor's link-local address. So, to identify the EIGRPv6 neighbor, you have to use that neighbor's link-local address (and not their EIGRPv6 RID).

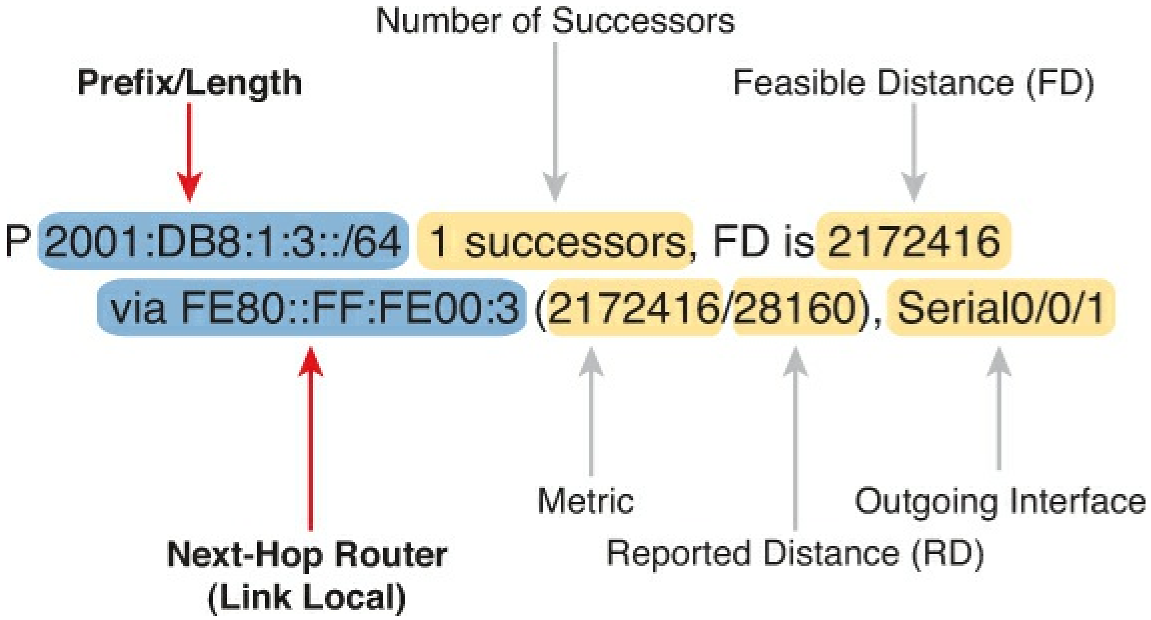
EIGRPv6 Topology Database

If you keep the discussions to topics within the scope of this book, once EIGRPv6 routers become neighbors, they should exchange all appropriate topology data. Outside the scope of this book, other router features can filter the topology data sent between routers. But for now, if the neighbor comes up, you can assume they exchange the topology data.

However, you should be ready to interpret the meaning of some of the topology data described by EIGRPv6. Thankfully, the EIGRPv6 topology data works just like it does for EIGRPv4, other than one obvious difference: It lists IPv6 prefixes. The following list points out the concepts that remain identical between the two:

- The metric components (bandwidth, delay, reliability, load).
- The metric calculation uses the same math.
- The idea of a successor route (the best route).
- The idea of FS routes.
- The feasibility condition, in which the reported distance (the composite metric reported by the neighbor) is lower (better) than the local router's metric.

For example, Figure 18-5 shows an excerpt from the output of the **show ipv6 eigrp topology** command. This output shows R1's topology data for subnet 3 (2001:DB8:1:3::/64), the subnet off R3's G0/0 LAN interface. The left side shows the two details particular to IPv6: the IPv6 prefix/length and the next-hop router's link-local address.



```
P 2001:DB8:1:3::/64 1 successors, FD is 2172416
        via FE80::FF:FE00:3 (2172416/28160), Serial0/0/1
```

Figure 18-5. Comparing IPv6 Details Versus Common Parts of EIGRP Topology Data

Note that while the left side shows the IPv6 prefix and IPv6 next-hop router address, the right side shows the exact same ideas as used with EIGRPv4. In fact, this example mirrors an example back in Chapter 10, shown there as Figure 10-4. That chapter also showed topology data from R1's database for the subnet off R3's G0/0 LAN interface. However, that example was for EIGRPv4 and for subnet 10.1.3.0/24. If you take the time to flip back to Figure 10-4, you will see the exact same information for all the data on the right based on the EIGRPv4 topology database, but IPv4 information about the subnet, mask, and next-hop address on the left.

In short, study Chapter 10's details about the metric components, the metric computed as a formula, the successor and FS, and so on. If you master those details for EIGRPv4, you have mastered the equivalent for EIGRPv6.

Example 18-9 shows the EIGRP topology table for one last insight into the internals of EIGRPv6. The output shows R1's detailed topology data for subnet 3 (2001:DB8:1:3::/64). Note that the first highlighted line lists the next-hop address and outgoing interface. It lists the composite metric—that is, the metric as calculated from the input of the various metric components—on the second highlighted line. The next two highlighted lines show the two metric components that impact the calculation (by default): bandwidth and delay. Finally, note that it mentions that EIGRP uses the minimum bandwidth (1544 Kbps) and the total delay (20,100).

Example 18-9. R2's EIGRPv6 Neighbors

Click here to view code image

```
R1# show ipv6 eigrp topology 2001:DB8:1:3::/64
EIGRP-IPv6 Topology Entry for AS(1)/ID(1.1.1.1) for 2001:DB8:1:3::/64
State is Passive, Query origin flag is 1, 1 Successor(s), FD is 2172416
Descriptor Blocks:
FE80::FF:FE00:3 (Serial0/0/1), from FE80::FF:FE00:3, Send flag is 0x0
Composite metric is (2172416/28160), route is Internal
Vector metric:
Minimum bandwidth is 1544 Kbit
Total delay is 20100 microseconds
Reliability is 255/255
Load is 1/255
Minimum MTU is 1500
Hop count is 1
Originating router is 3.3.3.3
FE80::FF:FE00:2 (Serial0/0/0), from FE80::FF:FE00:2, Send flag is 0x0
Composite metric is (2684416/2172416), route is Internal
Vector metric:
Minimum bandwidth is 1544 Kbit
Total delay is 40100 microseconds
Reliability is 255/255
Load is 1/255
Minimum MTU is 1500
Hop count is 2
```

EIGRPv6 IPv6 Routes

Verifying EIGRPv6-learned routes is relatively easy as long as you realize that the code for EIGRP is D and not E. Example 18-10 shows R1's entire IPv6 routing table, with six EIGRP-learned IPv6 routes.

Example 18-10. EIGRPv6 Routes on R1

Click here to view code image

```
R1# show ipv6 route
IPv6 Routing Table - default - 13 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
B - BGP, R - RIP, I1 - ISIS L1, I2 - ISIS L2
IA - ISIS interarea, IS - ISIS summary, D - EIGRP, EX - EIGRP external
ND - Neighbor Discovery, l - LISP
O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
C 2001:DB8:1:1::/64 [0/0]
via GigabitEthernet0/0, directly connected
L 2001:DB8:1:1::1/128 [0/0]
via GigabitEthernet0/0, receive
D 2001:DB8:1:2::/64 [90/2172416]
via FE80::FF:FE00:2, Serial0/0/0
D 2001:DB8:1:3::/64 [90/2172416]
via FE80::FF:FE00:3, Serial0/0/1
C 2001:DB8:1:4::/64 [0/0]
via Serial0/0/1, directly connected
L 2001:DB8:1:4::1/128 [0/0]
via Serial0/0/1, receive
C 2001:DB8:1:5::/64 [0/0]
via Serial0/0/0, directly connected
L 2001:DB8:1:5::1/128 [0/0]
via Serial0/0/0, receive
D 2001:DB8:1:6::/64 [90/2681856]
via FE80::FF:FE00:3, Serial0/0/1
via FE80::FF:FE00:2, Serial0/0/0
D 2001:DB8:1:7::/64 [90/2681856]
via FE80::FF:FE00:3, Serial0/0/1
D 2001:DB8:1:8::/64 [90/2681856]
via FE80::FF:FE00:2, Serial0/0/0
D 2001:DB8:1:33::/64 [90/2684416]
via FE80::FF:FE00:3, Serial0/0/1
```

```
    via FE80::FF:FE00:2, Serial0/0/0
    L FF00::/8 [0/0]
    via Null0, receive
```

The pair of highlighted lines about halfway through the example describes the one route to IPv6 subnet 3 (2001:DB8:1:3::/64). Each route lists at least two lines, with the first line listing the prefix/length and, in brackets, the administrative distance and the metric (feasible distance). The second line lists the forwarding instructions for a route.

When a router has multiple routes to reach one IPv6 prefix, the output shows one line with the prefix and then one line for each route. The line for each route lists the forwarding instructions (neighbor's link-local address and local router's outgoing interface). The highlighted lines at the end of the example, for subnet 33, show one such example, with two routes, each with a different next-hop address and different outgoing interface.

As for troubleshooting IPv6 routes, again, most of the troubleshooting for routes begins with questions about neighbors. Thinking through a potential EIGRPv6 problem actually follows the same logic as working through an OSPFv3 problem. Repeating some of the logic from the preceding chapter, when a router simply has no route to a given subnet—for instance, if R1 had no route at all for subnet 33—then do the following:

Step 1. Check the routers with interfaces directly connected to that IPv6 prefix. A router must have EIGRPv6 enabled on that interface before EIGRPv6 will advertise about the subnet.

Step 2. Check EIGRPv6 neighbor relationships for all routers between the local router and the routers with an interface connected to IPv6 prefix X.

For instance, in Figure 18-2, if router R4 did not have an **ipv6 eigrp 1** command under its G0/0 interface, all the routers would have their correct EIGRPv6 neighbor relationships, but R4 would not advertise about subnet 33.

If a router has a route, but it appears to be the wrong (suboptimal) route, take these steps:

Step 1. Check for broken neighbor relationships over what should be the optimal path from the local router and prefix Y.

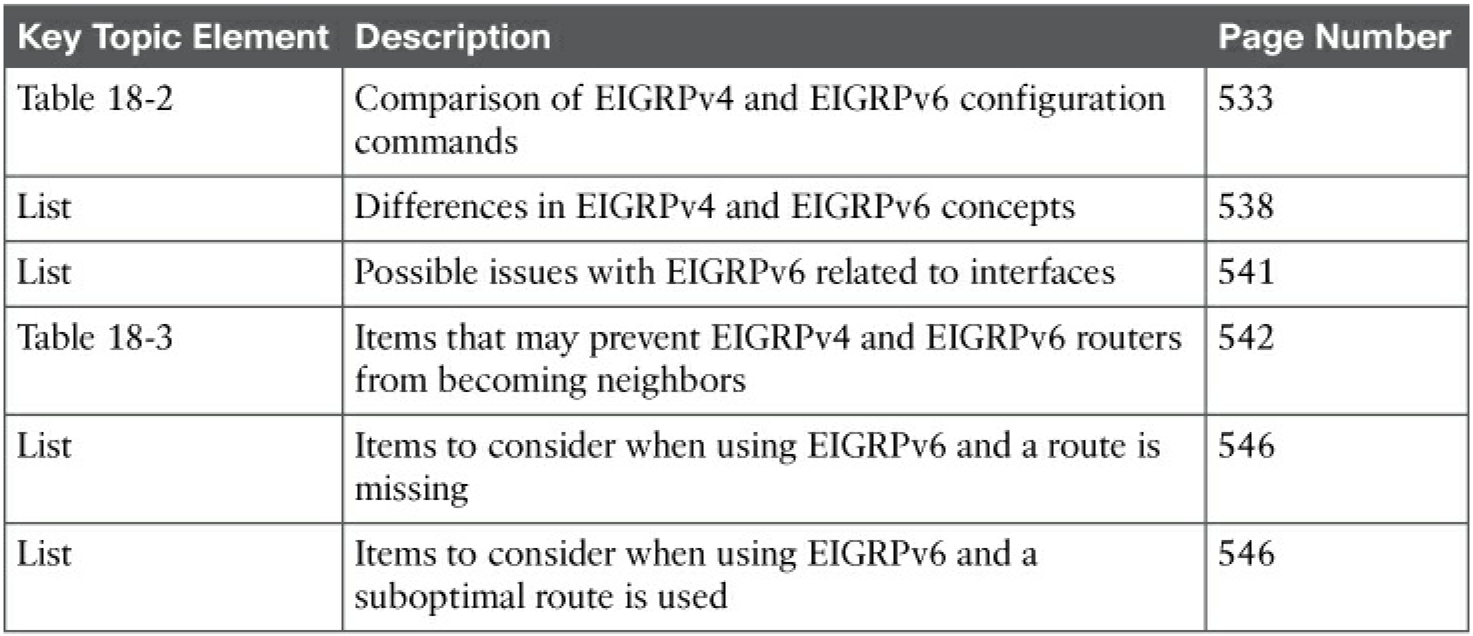
Step 2. Check the interface bandwidth and delay settings. Pay particular attention to the lowest bandwidth in the end-to-end route, because EIGRP ignores the faster bandwidths, using only the lowest (slowest) bandwidth in its metric calculation.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 18-4 lists these key topics and where each is discussed.

Table 18-4. Key Topics for Chapter 18



Key Topic Element	Description	Page Number
Table 18-2	Comparison of EIGRPv4 and EIGRPv6 configuration commands	533
List	Differences in EIGRPv4 and EIGRPv6 concepts	538
List	Possible issues with EIGRPv6 related to interfaces	541
Table 18-3	Items that may prevent EIGRPv4 and EIGRPv6 routers from becoming neighbors	542
List	Items to consider when using EIGRPv6 and a route is missing	546
List	Items to consider when using EIGRPv6 and a suboptimal route is used	546

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix D, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix E, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Definitions of Key Terms

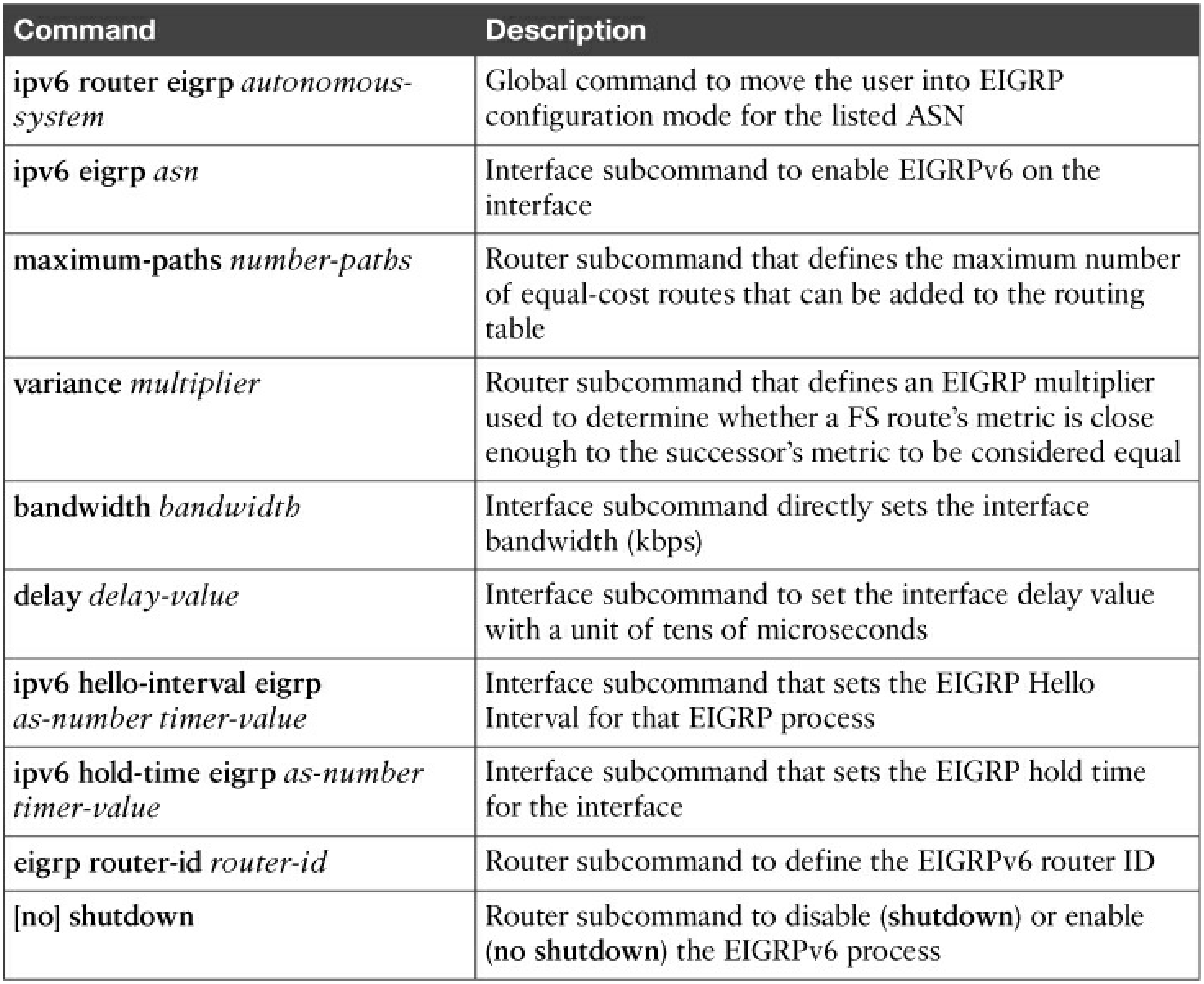
After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22 directs you in how to use these terms for late-stage preparation for the exam.

autonomous system number (ASN)
EIGRP for IPv6 (EIGRPv6)
successor
feasible successor

Command Reference to Check Your Memory

Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table, read the descriptions on the right side, and see if you remember the command.

Table 18-5. Chapter 18 Configuration Command Reference



Command	Description
ipv6 router eigrp *autonomous-system*	Global command to move the user into EIGRP configuration mode for the listed ASN
ipv6 eigrp *asn*	Interface subcommand to enable EIGRPv6 on the interface
maximum-paths *number-paths*	Router subcommand that defines the maximum number of equal-cost routes that can be added to the routing table
variance *multiplier*	Router subcommand that defines an EIGRP multiplier used to determine whether a FS route's metric is close enough to the successor's metric to be considered equal
bandwidth *bandwidth*	Interface subcommand directly sets the interface bandwidth (kbps)
delay *delay-value*	Interface subcommand to set the interface delay value with a unit of tens of microseconds
ipv6 hello-interval eigrp *as-number timer-value*	Interface subcommand that sets the EIGRP Hello Interval for that EIGRP process
ipv6 hold-time eigrp *as-number timer-value*	Interface subcommand that sets the EIGRP hold time for the interface
eigrp router-id *router-id*	Router subcommand to define the EIGRPv6 router ID
[**no**] **shutdown**	Router subcommand to disable (**shutdown**) or enable (**no shutdown**) the EIGRPv6 process

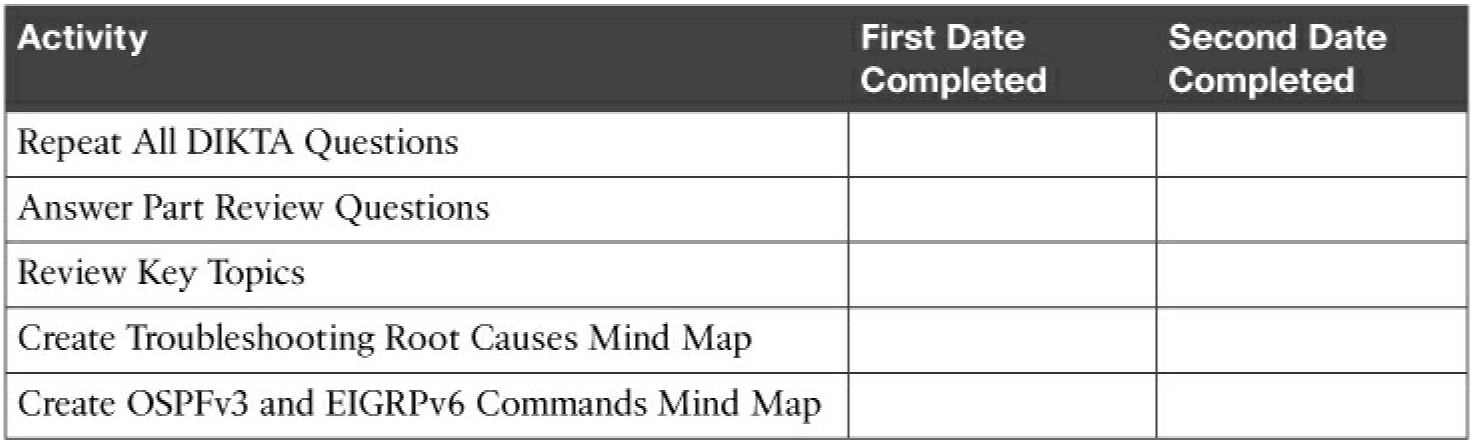
Table 18-6. Chapter 18 show **Command Reference**

Command	Description
show ipv6 eigrp interfaces	Lists one line per interface on which EIGRP has been enabled, but for which it is not made passive with the **passive-interface** configuration command
show ipv6 eigrp interfaces *type number*	Lists statistics interfaces on which EIGRP has been enabled, but for which it is not made passive with the **passive-interface** configuration command
show ipv6 eigrp interfaces detail [*type number*]	Lists detailed configuration and statistics, for all interfaces, or for the listed interface, again for enabled interfaces that are not passive
show ipv6 protocols	Shows brief information about each source of routing information, including listing interfaces enabled for EIGRPv6 and noting which interfaces are passive
show ipv6 eigrp neighbors	Lists EIGRP neighbors and status
show ipv6 eigrp neighbors *type number*	Lists EIGRP neighbors reachable off the listed interface
show ipv6 eigrp topology	Lists the contents of the EIGRP topology table, including successors and feasible successors
show ipv6 eigrp topology *prefix/length*	Lists detailed topology information about the listed prefix
show ipv6 eigrp topology | section *prefix/length*	Lists a subset of the **show ipv6 eigrp topology** command: just the section for the listed prefix/length
show ipv6 route	Lists all IPv6 routes
show ipv6 route eigrp	Lists routes in the IPv6 routing table learned by EIGRPv6
show ipv6 route *prefix/length*	Shows a detailed description of the route for the listed prefix/length
show ipv6 route | section *prefix*	Lists a subset of the **show ip route** command (just the section for the listed prefix)

Part V Review

Keep track of your part review progress with the checklist in Table P5-1. Details about each task follow the table.

Table P5-1. Part V Part Review Checklist



Activity	First Date Completed	Second Date Completed
Repeat All DIKTA Questions		
Answer Part Review Questions		
Review Key Topics		
Create Troubleshooting Root Causes Mind Map		
Create OSPFv3 and EIGRPv6 Commands Mind Map		

Repeat DIKTA Questions

For this task, answer the "Do I Know This Already?" questions again for the chapters in Part I of this book using the PCPT software. See the section "How to View Only DIKTA Questions by Part" in the Introduction to this book to learn how to make the PCPT software show you DIKTA questions for this part only.

Answer Part Review Questions

For this task, answer the Part Review questions for this part of the book using the PCPT software. See the section "How to View Only DIKTA Questions by Part" in the Introduction to this book to learn how to make the PCPT software show you DIKTA questions for this part only.

Review Key Topics

Key Topic

Browse back through the chapters, and look for the Key Topic icons. If you do not remember some details, take the time to reread those topics.

Create Troubleshooting Root Causes Mind Map

Chapter 16, "Troubleshooting IPv6 Routing," focuses on how to troubleshoot IPv6 routing problems while ignoring Open Shortest Path First Version 3 (OSPFv3) and Enhanced Interior Gateway Routing Protocol Version 6 (EIGRPv6). Then, Chapters 17, "Implementing OSPF for IPv6," and 18, "Implementing EIGRP for IPv6," fold in the troubleshooting discussion for these two routing protocols.

For this first Part Review mind map, try to collect all root causes of problems in an IPv6 network and organize those into a mind map. As usual, use short reminders, rather than long descriptions, with just enough information for you to remember the meaning. Also, organize the concepts in a way that makes sense to you. And avoid looking at the chapters when first building these; as usual, the point is to help you organize the ideas in your own head, rather than to read lists from the book again.

If you want a little guidance, you can organize the topics based on the chapters. To match the chapters, put EIGRPv6 troubleshooting in one part of the mind map, OSPFv3 in another, and IPv6 routing in a third.

> **Note**
>
> For more information about mind mapping, see the section "About Mind Maps" in the Introduction to this book.

Create OSPFv3 and EIGRPv6 Commands Mind Map

This part also discussed both OSPFv3 and EIGRPv6 configuration and verification. Create a command mind map, like in many other part reviews. The first level of organization should be for OSPFv3 versus EIGRPv6, then for configuration versus verification. Inside the verification area, further organize the commands related to interfaces, neighbors, topology, and routes. (Note that you made similar mind maps for Part III review, for the IPv4 versions of these routing protocols.)

DVD Appendix F, "Mind Map Solutions," lists sample mind map answers, but as usual, your mind maps can and will look different.

Part VI: Network Management

Chapter 19: Managing Network Devices

Chapter 20: Managing IOS Files

Chapter 21: Managing IOS Licensing

Part VI Review

Part VI of this book examines a wide variety of small topics, all related in some way to managing the network and the devices in the network. The topics include network management with SNMP, managing network traffic with NetFlow, managing informational messages with syslog, manipulating IOS images on routers, and managing software features and licenses.

Chapter 19. Managing Network Devices

This chapter covers the following exam topics:

IP Services

Configure and verify Syslog

Utilize Syslog Output

Describe SNMP v2 & v3

Troubleshooting

Utilize netflow data

Monitor NetFlow statistics

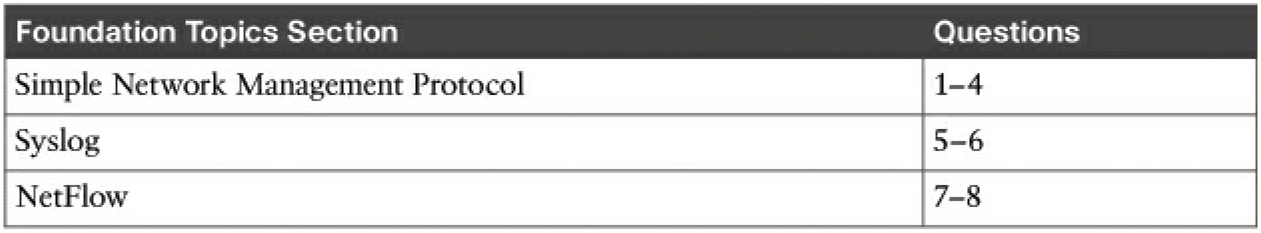
The modern network is called upon to do so much. No longer is it adequate to simply transmit the data (spreadsheets, transactions, documents) that a company needs to carry out its operations. Often, networks must also carry the voice and video traffic of an organization. These networks must be faster and more reliable than ever. They must be highly available and must scale at the snap of a manager’s fingers. Although this might seem daunting, the excellent news is that a wide range of mature and highly useful network management protocols and techniques can aid an administrator of even the most complex networks.

This chapter explores three predominate tools in the field of network management for Cisco devices. A proper implementation of Simple Network Management (SNMP), system message logging (syslog), and NetFlow can ease a Cisco administrator’s workload and overall stress levels (and even help save his or her job). Protocols and best practices in these areas can help the admin be *proactive* rather than *reactive*. Proactive network management will indeed be a major theme of this chapter that should serve the reader very well.

“Do I Know This Already?” Quiz

Use the “Do I Know This Already?” quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the “Exam Preparation Tasks” section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, “Answers to the ‘Do I Know This Already?’ Quizzes.”

Table 19-1. “Do I Know This Already?” Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Simple Network Management Protocol	1–4
Syslog	5–6
NetFlow	7–8

1. What is the name of the database that runs on network devices and can be accessed with an SNMP agent?
   a. The NetFlow Repository
   b. The Management Store
   c. The Management Variable Store
   d. The Management Information Base
2. Which software package is an example of an NMS that can rely on SNMP?
   a. Cisco Monitor
   b. Cisco Insight
   c. Cisco Prime
   d. Cisco View
3. Which command configures a device to be monitored, but not configured, by version 2c of SNMP using a community string of CiscoSanFran?
   a. snmp-server secret CiscoSanFran ro
   b. snmp-server community CiscoSanFran ro
   c. snmp-server 2c community CiscoSanFran read-only
   d. snmp-server 2c community CiscoSanFran monitor-only
4. Which SNMP Version 3 mode relies on a username for authentication and does not feature encryption?
   a. noAuthPriv
   b. AuthPriv
   c. noAuthNoPriv
   d. AuthOnly
5. What level of logging to the console is the default for a Cisco device?

    a. Informational
    b. Errors
    c. Warnings
    d. Debugging

6. What command limits the messages sent to a syslog server to levels 4 through 0?
    a. logging trap 0-4
    b. logging trap 1,2,3,4
    c. logging trap 4
    d. logging trap through 4

7. Which item is not used by NetFlow to identify a flow?
    a. Destination port number
    b. Type of Service (ToS) marking
    c. Layer 3 protocol type
    d. Output logical interface

8. Which command ensures that NetFlow captures egress traffic statistics under an interface?
    a. ip netflow egress
    b. ip flow out
    c. ip flow egress
    d. ip netflow egress

Answers to the "Do I Know This Already?" quiz:

1 D **2** C **3** B **4** C **5** D **6** C **7** D **8** C

Foundation Topics

Simple Network Management Protocol

The year was 1988 and RFC 1065 was published: *Structure and Identification of Management Information for TCP/IP-based Internets*. The superb idea behind this document was the fact that devices on a TCP/IP-based network could be broken down into a database of variables and that these variables could be monitored to manage the overall IP-based network. After all, the elements of any IP-based machines would have commonalities. For example, a PC, a network printer, and a router would all have commonalities such as interfaces, IP addresses, and buffers. Why not create a standardized database of these variables and a simple system for monitoring and managing them? This idea was brilliant, caught on, and became three different versions of the Simple Network Management Protocol (SNMP).

Describing SNMP

Simple Network Management Protocol is an application layer protocol that provides a message format for communication between what are termed managers and agents. An SNMP manager is a network management application running on a PC, and the agent is software running on the device that is to be managed. The agent's job is to retrieve (or optionally write) to the variables stored in the database of variables that make up the parameters of the device. This database is called the Management Information Base (MIB). Cisco Prime is a classic example of an SNMP manager. A Cisco router might run the SNMP agent, and a MIB variable might be the load on the router's interface. Figure 19-1 shows these elements of an SNMP environment.

Key Topic

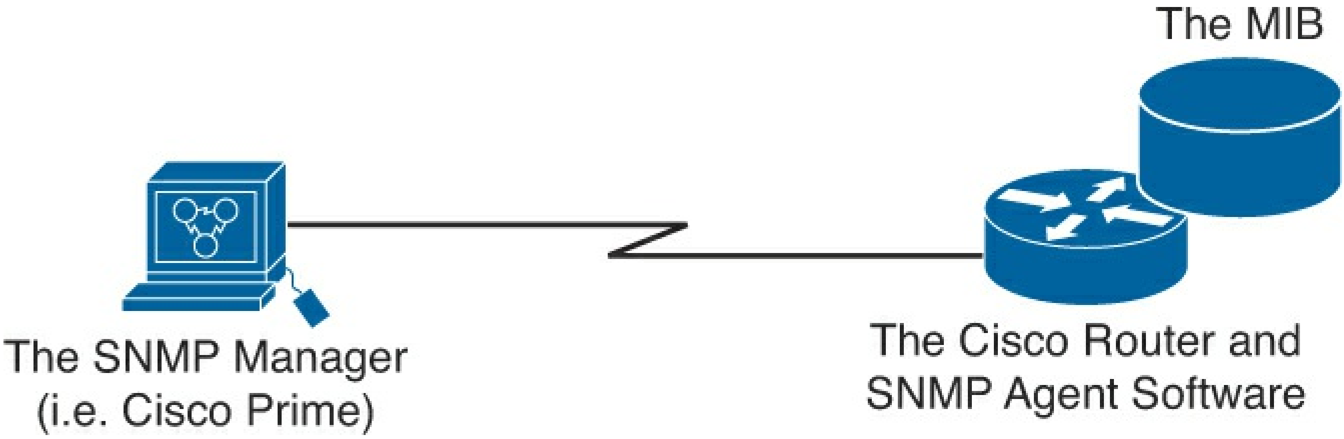


Figure 19-1. Elements of Simple Network Management Protocol

Through the process of periodically querying or polling the SNMP agent on a device, you can gather and analyze statistics about the managed device. You can even reconfigure the device through these SNMP variables in the MIB if you permit this level of control. The messages that poll information from the SNMP agent software are termed GET messages, and the messages that write variables are termed SET messages.

SNMP permits much flexibility in how you monitor variables in the MIB. Most commonly, a network administrator gathers and stores statistics over time using Network Management Station (NMS) software like Cisco Prime. Important to these administrators is to analyze various statistical facts such as averages, minimums, and maximums. To be proactive, administrators can set thresholds for certain key variables. They can then be dynamically notified by the NMS when a value is nearing unacceptable values. Figure 19-2 demonstrates the use of SNMP for proactive network management.

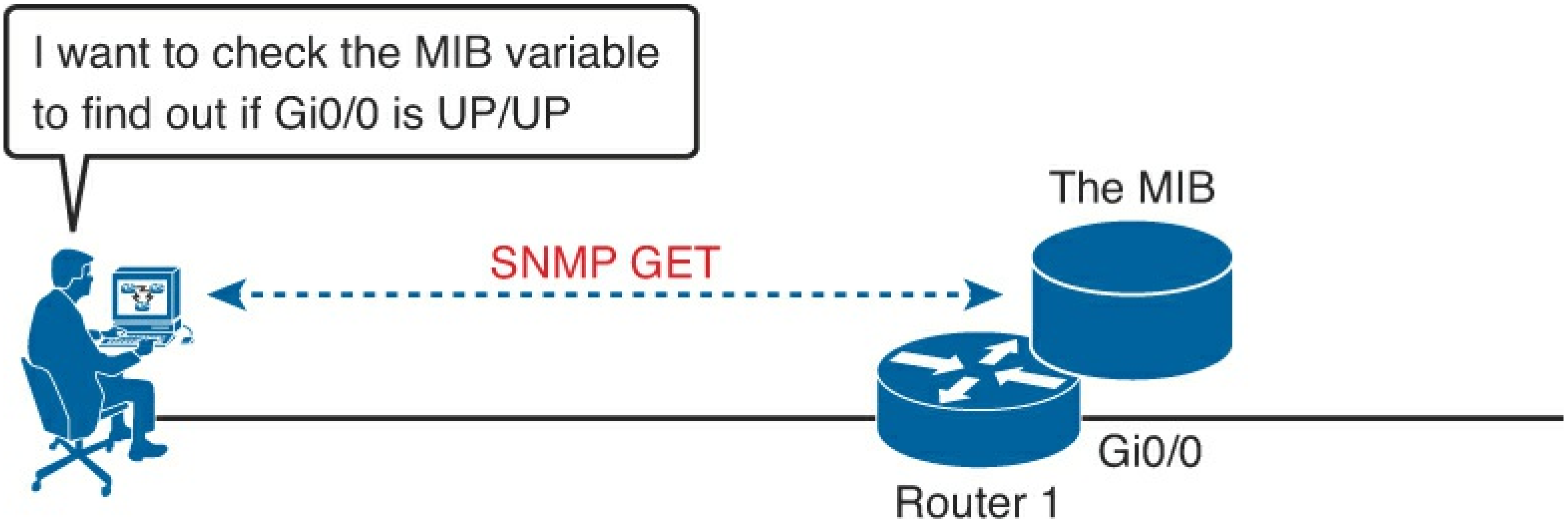

I want to check the MIB variable
to find out if Gi0/0 is UP/UP
SNMP GET
The MIB
Gi0/0
Router 1

Figure 19-2. SNMP in Use for Monitoring the Network

An excellent example of this style of network management is monitoring the CPU utilization on a Cisco router. Thanks to SNMP, the NMS can sample this value periodically and present this information in a graph for the network administrator. This information creates a baseline for administrators so that they can easily see when CPU utilization is driving away from normal values for the network.

In addition to consistently polling an SNMP managed device for its MIB variable information, using the GET SNMP command, the device itself can independently notify the NMS when a problem occurs using SNMP *traps*. Traps are SNMP messages that are sent from the network device that also list the state of a MIB variable; but because the device decides to send the information without being asked, the NMS can react differently.

For instance, suppose that router 1's G0/0 interface fails, as shown at Step 1 of Figure 19-3. With traps configured, the router would send an SNMP trap message to the NMS, with that trap message noting the down state of the G0/0 interface. Then the NMS software can send a text message to the network support staff, pop a window on the NMS screen, turn the correct router icon red on the graphical interface, and so on.

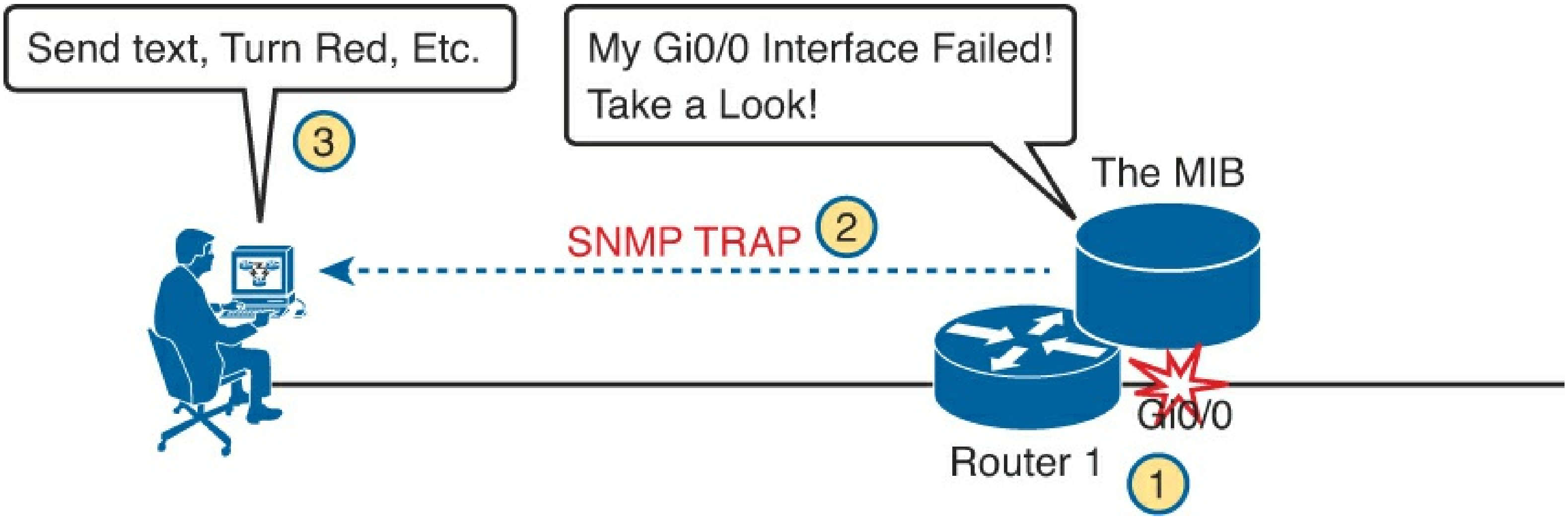

Send text, Turn Red, Etc.
③
My Gi0/0 Interface Failed! Take a Look!
The MIB
SNMP TRAP
②
Gi0/0
Router 1
①

Figure 19-3. SNMP in Use for Monitoring the Network

SNMP provides two options to send these unsolicited messages from a managed device to the NMS. Figure 19-3 shows the trap message. Devices send trap messages with no acknowledgment that the NMS received the message; using protocol terminology, these messages are considered unreliable. A later version of the SNMP protocols (Version 3) supports an alternative process with inform messages, which use an acknowledgment process, so they are called reliable.

The Management Information Base

As mentioned in the earlier discussion, the Management Information Base (MIB) defines variables, and those variables enable the management software to monitor/control the network device. Formally, the MIB defines each variable as an object ID (OID). The MIB then organizes the OIDs based on RFC standards into a hierarchy of OIDs, usually shown as a tree.

The MIB for any given device includes some branches of the MIB tree with variables common to many networking devices and branches with variables specific to that device. RFCs define some common public variables, and most all devices implement these MIB variables. In addition, networking equipment vendors like Cisco can define their own private branches of the tree to accommodate new variables specific to their own devices.

Figure 19-4 shows portions of the MIB structure defined by Cisco Systems. Note how the OID can be described in words or numbers to locate a particular variable in the tree.

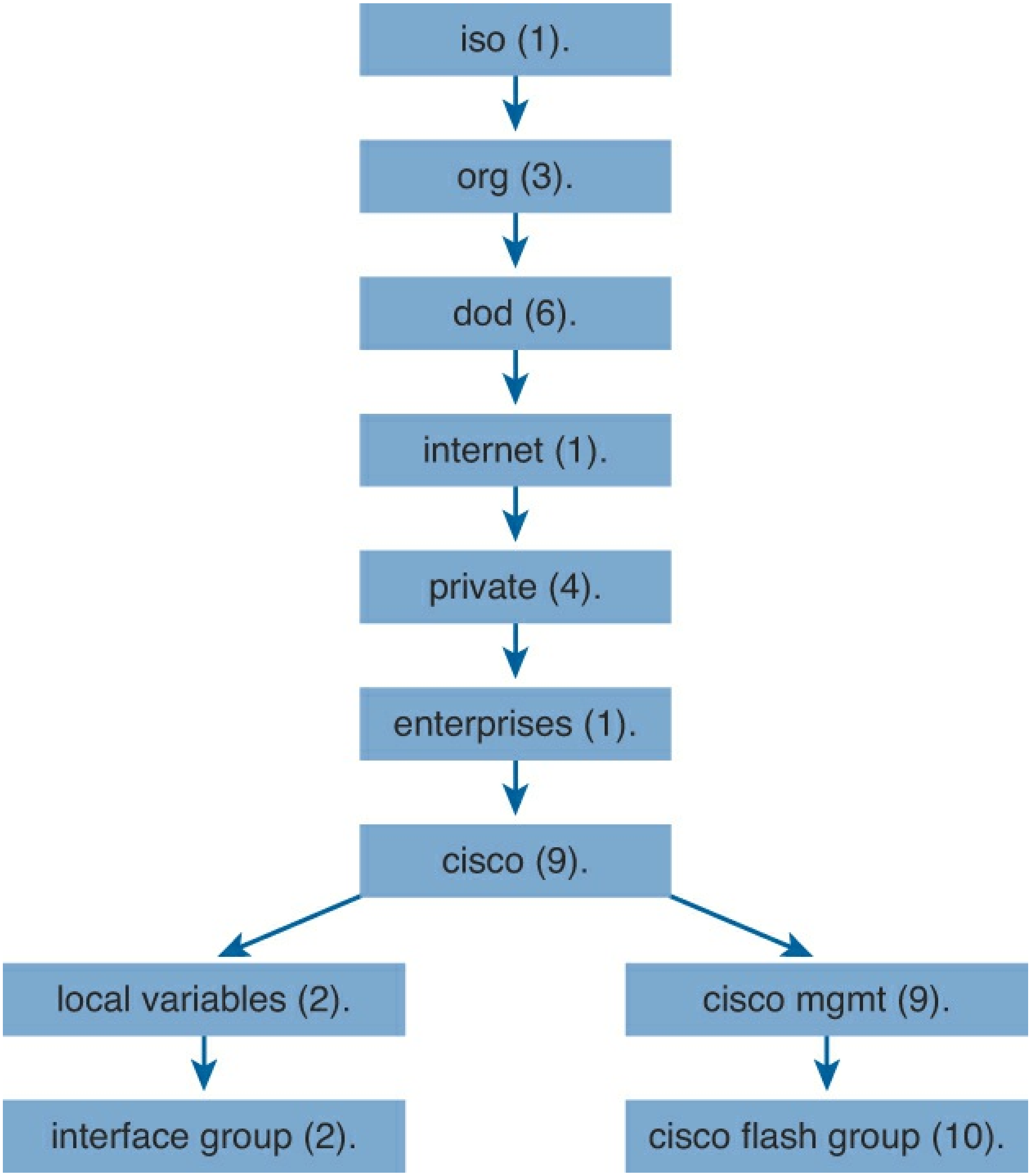

iso (1).
org (3).
dod (6).
internet (1).
private (4).
enterprises (1).
cisco (9).
local variables (2).
cisco mgmt (9).
interface group (2).
cisco flash group (10).

Figure 19-4. The Management Information Base (MIB)

As another example of a tool you can try in your home lab, the freeware SNMPGET utility allows quick retrieval of information from the MIB. In Example 19-1, the SNMPGET utility is used on a PC to obtain the 5-minute exponential moving average of the CPU busy percentage from a router.

Example 19-1. Obtaining a MIB Value with SNMPGET

Click here to view code image

```
[13:22][cisco@NMS~ ]$ snmpget -v2c -c community 10.250.250.14
1.3.6.1.4.1.9.2.1.58.0
SNMPv2-SMI::enterprises.9.2.1.58.0 = INTEGER: 11
```

The bold text shows a rather long command with several parameters, as follows:

-v2c: The version on SNMP in use

-c community: The SNMP password, called a community sting

10.250.250.14: The IP address of the monitored device

1.3.6.1.4.1.9.2.1.58.0: The numeric object identifier (OID) of the MIB variable

The last line shows the response. The output shows a shortened version of the of the MIB variable. It then lists the actual value in the MIB location—in this case, the 5-minute exponential moving average of the CPU busy percentage (11 percent).

The utility shown in Example 19-1 gives some insight into the basic mechanics of how SNMP works. However, working with long MIB variable names like 1.3.6.1.4.1.9.2.1.58.0 could be a real problem for the average user. More commonly, the network operations staff uses a network management product like Cisco Prime, with its easy-to-use graphical interface, with all the MIB data variable naming hidden from the typical user.

Configuring SNMP Version 2c

The three main versions of SNMP used throughout the years are Versions 1, 2c, and 3. Because Version 1 is extremely legacy, and not often encountered in networks today, this text focuses on Versions 2c and 3.

SNMP Version 2c had several enhancements over the first version. Many of these were improvements in the messaging system to make obtaining large amounts of statistics from the device more efficient. Unfortunately, not much was done in the area of security.

Both SNMP Version 1 and SNMP Version 2c rely on what are termed SNMP *community strings* to authenticate access to MIB objects. These community strings are really just clear-text passwords. These days, clear-text passwords are really not even considered a security mechanism because they are so vulnerable to a man-in-the-middle attack in which they are compromised through the capture of packets.

There are two types of community strings in SNMP Version 2c:

Read-only (RO): Provides access to the MIB variables, but does not allow these variables to changed, only read. Because security is so weak in Version 2c, many organizations only use SNMP in this read-only mode.

Read-write (RW): Provides read and write access to all objects in the MIB.

Note

SNMP security is not truly provided until Version 3. This version is described later in the chapter.

Configuring SNMP Version 2c on a Cisco router or switch requires only one configuration command: the **snmp-server community** global command. However, most SNMP configurations include a couple of optional settings, as well. The following configuration checklist identifies the common steps:

Key Topic

Step 1. (Required) Configure the community string and access level (read-only or read-write) with the **snmp-server community** *string* **RO|RW** global command.

Step 2. (Optional) Document the location of the device using the **snmp-server location** *text-describing-location* global configuration command.

Step 3. (Optional) Document the location of the device using the **snmp-server contact** *contact-name* global configuration command.

Step 4. (Optional) Restrict SNMP access to NMS hosts that are permitted by an access control list (ACL) by defining an ACL and referencing the ACL on the **snmp-server community** *string acl-name-or-number* global configuration command.

Example 19-2 uses the one required command plus the other optional commands from the list. It uses a difficult-to-guess community string, allows access from only the NMS at address 10.10.10.101, and defines the location and contact name for this device (router R1).

Key Topic

Example 19-2. Configuring SNMP Version 2c for Read-Only Access

Click here to view code image

```
R1(config)# ip access-list standard ACL_PROTECTSNMP
R1(config-std-nacl)# permit host 10.10.10.101
R1(config-std-nacl)# exit
R1(config)# snmp-server community V011eyB@11!!! RO ACL_PROTECTSNMP
R1(config)# snmp-server location Tampa
R1(config)# snmp-server contact Anthony Sequeira
R1(config)# end
R1#
```

Example 19-3 adds a similar configuration to router R2, located in New York. The example allows a different NMS (also in New York) to manage the router, and in this case, it allows read/write (RW) access.

Example 19-3. Configuring SNMP Version 2c for Read and Write Access

Click here to view code image

```
R2(config)# ip access-list standard ACL_PROTECTSNMP
R2(config-std-nacl)# permit host 10.20.20.201
R2(config-std-nacl)# exit
R2(config)# snmp-server community T3nn1sB@ll RW ACL_PROTECTSNMP
R2(config)# snmp-server location New York
R2(config)# snmp-server contact John Sequeira
R2(config)# end
R2#
```

The choice of read-only SNMP access on router R1, and read-write access on router R2, has a much bigger impact on operation of the network than you might guess from just one small difference in the configuration. Routers and switches that allow read-write access allow the NMS to change the configuration of the router or switch. For instance, with read-write access, the NMS can shut down an interface or bring it up again, whereas read-only access does not allow changes to the configuration.

SNMP Version 3

SNMP Version 3 arrived with much celebration among network administrators. Finally, security arrived with the powerful network management protocol. The security features provided in SNMPv3 are as follows:

- **Message integrity**: This helps ensure that a packet has not been tampered with in transit.
- **Authentication**: This helps ensure that the packet came from a known and trusted source.
- **Encryption**: This helps to ensure that information cannot be read if the data is captured in transit.

This list defines what the SNMPv3 protocol can do as a whole, but devices can choose to implement only some of these features, based on the configuration. However, even the least secure SNMPv3 option improves security compared to SNMPv2c, with the managed device requiring a username to identify the user (the NMS). As shown in Table 19-2, each SNMPv3 security level offers a different combination of security features, including protecting the authentication with a hash and encrypting the data that is sent between the device and the NMS.

Table 19-2. Possible Security Modes of SNMP Version 3

Level Name	Keyword in snmp-server Command	Authentication Method	Encryption
noAuthNoPriv	**noauth**	Username	None
authNoPriv	**auth**	Message Digest 5 (MD5) or Secure Hash Algorithm (SHA)	None
authPriv	**priv**	Message Digest 5 (MD5) or Secure Hash Algorithm (SHA)	DES or DES-56

> **Note**
>
> Even the noAuthNoPriv level is an improvement over SNMP Version 2c because activity can be tracked to a certain user account.

System Message Logging (Syslog)

It is amazing just how helpful Cisco devices try to be to their administrators. When major (and even not-so-major) events take place, these Cisco devices attempt to notify administrators with detailed system messages. As you learn in this section, these messages vary from the very mundane to those that are incredibly important. Thankfully, administrators have a large variety of options for storing these messages and being alerted to those that could have the largest impact on the network infrastructure.

An Overview of System Message Logging

The most common method of taking advantage of this wealth of system messages that Cisco devices provide is to use a protocol called syslog. Syslog permits your various Cisco devices (and some other non-Cisco devices) to send their system messages across the network to syslog servers. You should note that you can even build a special out-of-band (OOB) network for this purpose. There are many different Syslog server software packages for Windows and UNIX. Many of them are even freeware.

Internally, Cisco network devices send system messages and debug output to a local logging process inside the device. You can then dictate (using configuration) what this logging process does with these messages. For example, you might want them sent across the network to a syslog server, as described earlier. Or perhaps you would like them sent to an internal buffer so that you can view them at your convenience at a later time right through the device CLI. You can even specify that only certain types of system messages are sent to various destinations. For example, perhaps you do not want debug-level messages sent to the external syslog server because you always plan to observe those messages at the CLI.

Popular destinations for syslog messages include the following:

- The logging buffer (RAM inside the router or switch)
- The console line
- The terminal lines
- A syslog server

Figure 19-5 shows various Cisco devices sending system messages to a syslog server.

Key Topic

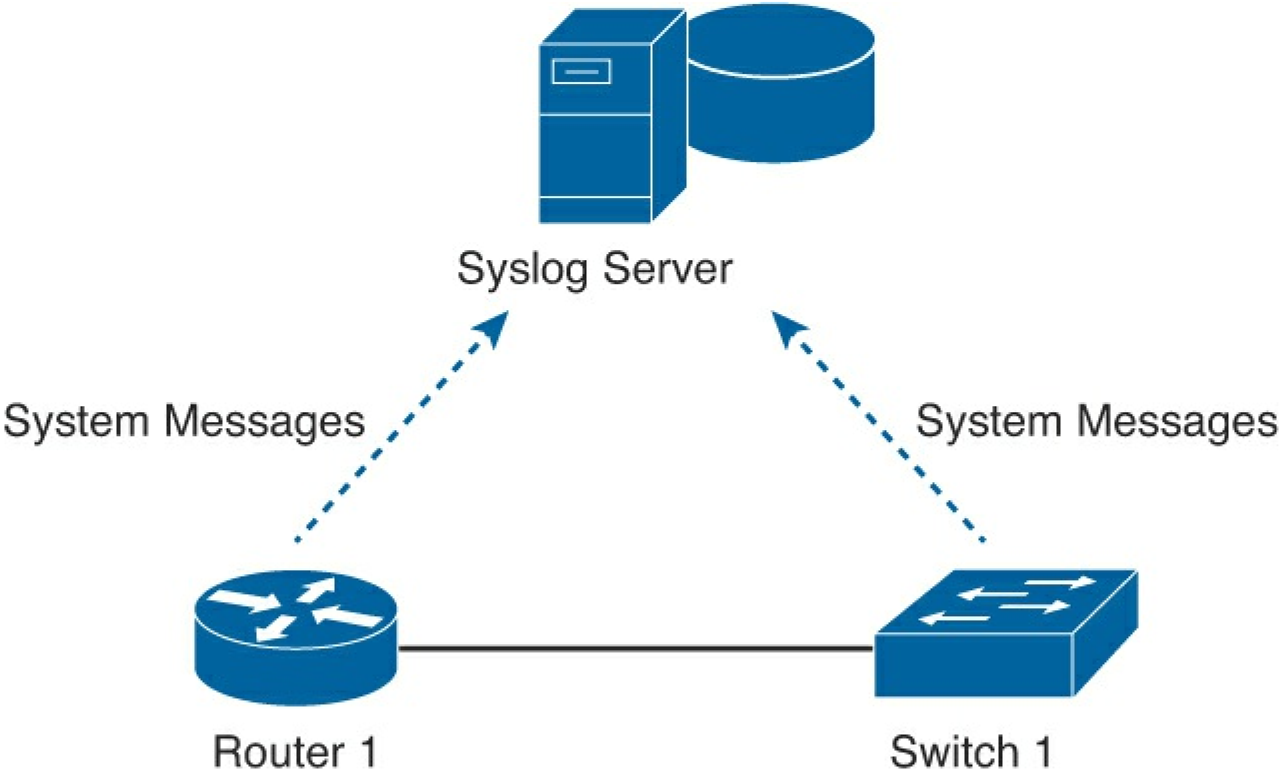


Figure 19-5. Syslogging in the Network

System Message Format

Let’s examine one of the messages from our Cisco router to examine the default message format:

```
*Dec 18 17:10:15.079: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet0/0, changed state to down
```

Notice that by default on this particular device, we see the following:

- **A timestamp:** *Dec 18 17:10:15.079
- **The facility on the router that generated the message:** %LINEPROTO
- **The severity level:** 5
- **A mnemonic for the message:** UPDOWN
- **The description of the message:** Line protocol on Interface FastEthernet0/0, changed state to down

You have now seen the default system message format on a particular Cisco router, but you should know that you can control the format of your messages. For example, we can turn off timestamps and turn on sequence numbers, as shown in Example 19-4.

Example 19-4. Modifying System Messages

[Click here to view code image]

```
R1(config)# no service timestamps
R1(config)# service sequence-numbers
R1(config)# end
R1#
000011: %SYS-5-CONFIG_I: Configured from console by console
```

As usual, when a user exits configuration mode, the router issues yet another system message, as shown at the end of the example. Comparing this message to the previous example, it now no longer lists the time of day, but does list a sequence number. The message format now features the following:

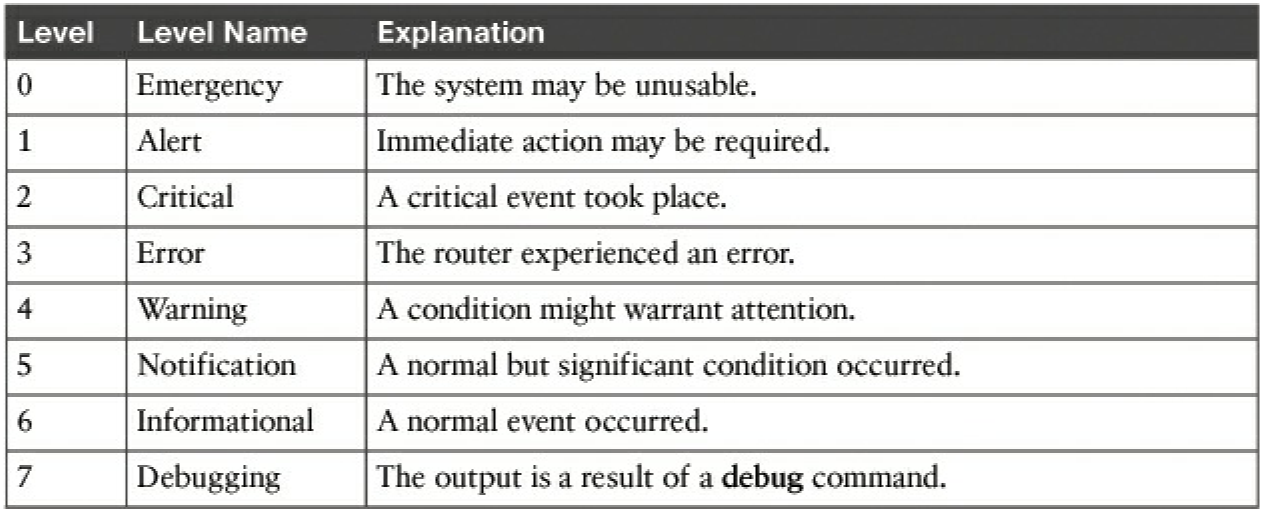
- **Sequence number:** 000011
- **Facility:** %SYS
- **Severity level:** 5
- **Mnemonic:** Config_I
- **Description:** Configured from console by console

System Message Severity Levels

By far, one of the most important ingredients in the system message on a Cisco device is the severity level. This is because we can use severity levels to easily control which messages are sent to which logging destinations. Table 19-3 details the various system message severity levels that are possible on a Cisco device.

Key Topic

Table 19-3. System Message Severity Levels



Level	Level Name	Explanation
0	Emergency	The system may be unusable.
1	Alert	Immediate action may be required.
2	Critical	A critical event took place.
3	Error	The router experienced an error.
4	Warning	A condition might warrant attention.
5	Notification	A normal but significant condition occurred.
6	Informational	A normal event occurred.
7	Debugging	The output is a result of a **debug** command.

Notice that levels 0 through 4 are for events that could seriously impact the device, whereas levels 5 through 7 are for less-important events. Obviously, an administrator can consider this when deciding how to handle messages. For instance, the administrator could choose to send only warning level (4) messages and lower (more severe) to the syslog server, instead of cluttering the syslog server with messages for all eight levels.

Configuring and Verifying Syslog

By default, Cisco routers and switches send log messages for all severity levels to the console. On some IOS versions, the device also buffers those log messages by default. To enable these two settings, the configuration would use the **logging console** and **logging buffered** global configuration commands, respectively. To disable either of these logging services, just use the **no** version of either command: **no logging console** or **no logging buffered**.

The **show logging** command lets us examine the logging service settings on a Cisco router, as shown in Example 19-5. The first lines of output list information about the logging process, with the end of the output listing log messages.

Example 19-5. Viewing the Default Logging Service Settings on a Cisco Router

[Click here to view code image]

```
R1# show logging
Syslog logging: enabled (0 messages dropped, 2 messages rate-limited,0 flushes, 0 overruns, xml disabled,
filtering disabled)
No Active Message Discriminator.
No Inactive Message Discriminator.
Console logging: level debugging, 10 messages logged, xml disabled, filtering disabled
Monitor logging: level debugging, 0 messages logged, xml disabled, filtering disabled
Buffer logging: level debugging, 10 messages logged, xml disabled,filtering disabled
Logging Exception size (8192 bytes)
Count and timestamp logging messages: disabled
Persistent logging: disabled
No active filter modules.
ESM: 0 messages dropped
Trap logging: level informational, 13 message lines logged
Log Buffer (8192 bytes):
*Dec 18 17:10:14.079: %LINK-3-UPDOWN: Interface FastEthernet0/0, changed state to down
*Dec 18 17:10:15.079: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet0/0, changed state to down
...
```

Focus on the first two highlighted lines, which tell us something about the logging service. The first line states that this router logs to the console and will include debug messages, actually meaning debug level messages and all lower levels; see Table 19-3 for the list of levels. The output also notes that ten such messages have been logged. The second highlighted line states that this router logs to an internal buffer.

Because this router has enabled logging to an internal buffer, the **show logging** command also lists the messages in that buffer. You can see some of the system messages that have been logged at the end of the example.

Configuring the router to send system messages to a syslog server where they can be stored, filtered, and analyzed is a simple task:

Step 1. First, configure the destination hostname or IP address of the syslog server:

```
R1(config)# logging 192.168.1.101
```

Step 2. Next, you can control which messages are sent there. For example, to limit the messages for levels 4 and lower (0 through 4), use the following command:

```
R1(config)# logging trap 4
```

> **Note**
>
> Notice that by specifying the highest level (least severe), this includes the levels below (more severe). Also, this command can also accept the name of the level, so you could use **logging trap warning**.

Using a Syslog Server

Logging to the device’s internal buffer is the most efficient method of handling system messages, but the most popular is to log messages to syslog server software.

Syslog servers log the messages and usually provide an easy means to display and sort the messages for easier troubleshooting.

Thanks to syslog servers, administrators can easily use the wealth of information presented in system messages. They can search for messages with certain keywords or severity levels. They can easily script email of text alerts based on the receipt of a certain message/severity.

Of course, administrators can also use syslog server software to delete all of those system messages from the database that are not important. Once again, a key aspect of using the output of system messages is wading through all of the messages that do not provide useful information.

NetFlow

Even with such powerful network management tools like Simple Network Management Protocol (SNMP), it quickly became apparent to Cisco engineers that networking professionals would need a simple and efficient method for tracking TCP/IP flows in the network. This information could be used to easily identify potential network bottlenecks, guide network improvements and redesigns, and could even assist in billing consumers of the network. Because of these needs, Cisco invented NetFlow. This powerful network protocol quickly became a standard, and it is now supported by other networking giants.

An Overview of NetFlow

Whereas network protocols such as SNMP attempt to provide a very wide range of network management features and options, NetFlow is simple and specific in its mission: to as efficiently as possible provide statistics on IP packets flowing through network devices.

For instance, in Figure 19-6, host A connects to host B using some application (for instance, HTTP). NetFlow can monitor that application connection (counting packets, bytes, and so on) for that individual application flow. It can then push the statistics over to an external server called a NetFlow collector.

Key Topic

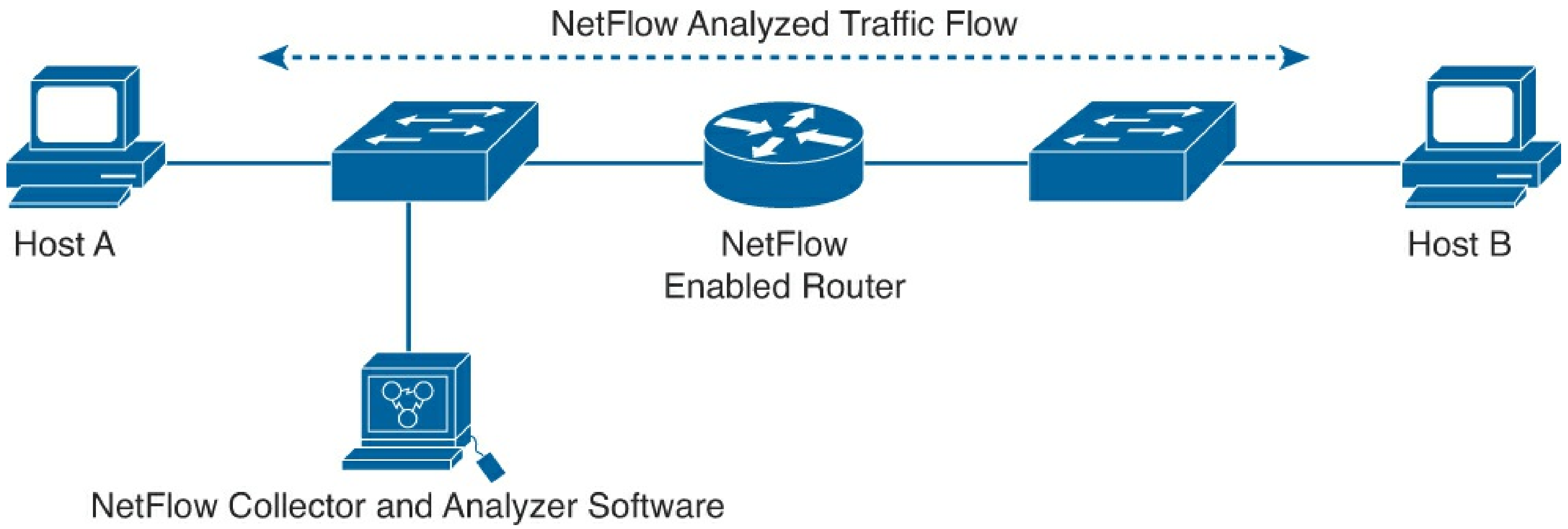

NetFlow Analyzed Traffic Flow
Host A
NetFlow
Enabled Router
Host B
NetFlow Collector and Analyzer Software

Figure 19-6. NetFlow in the Typical Network

While the potential uses of the statistics that NetFlow provides is quite vast, most organizations use NetFlow for some or all of the following key purposes:

- General network traffic accounting for baseline analysis
- Usage-based network billing for consumers of network services
- Network design, including redesigns to include new network devices and applications to meet the needs of growing infrastructures
- General network security design
- Denial of service (DoS) and distributed DoS (DDoS) detection and prevention data
- Ongoing network monitoring

While you can think of a network management protocol like SNMP as remote-control software for an unmanned vehicle, an excellent and often-used analogy for NetFlow is a simple, yet detailed phone bill. These phone records provide call-by-call and aggregated statistics that enable the administrator (the person paying the bill) to track long calls, frequent calls, or even calls that should not have been made at all.

> **Note**
>
> It is important not to confuse NetFlow with the purpose and results for packet-capture hardware and software. Whereas packet captures record all possible information exiting or entering a network device for later analysis, NetFlow targets specific statistical information.

When Cisco sought out to create NetFlow, they recognized two key criteria in its creation:

- NetFlow should be completely transparent to the applications and devices in the network.
- NetFlow should not have to be supported and running on all devices in the network to function.

Achieving these design criteria ensured that NetFlow is very easy to implement in the most complex of existing networks.

> **Note**
>
> Although NetFlow is simple to implement and transparent to the network, it does consume additional memory on the Cisco router. This is because NetFlow stores record information in "cache" on the device. The default size of this cache varies based on the platform, and the administrator can adjust this value.

Network Flows

A key to NetFlow, as its name implies, is the fact that it breaks down TCP/IP communications for statistical record keeping using the concept of a flow. What is a flow according to the NetFlow application? A flow is a unidirectional stream of packets between a specific source system and a specific destination system. For NetFlow, obviously built around TCP/IP, the source and destination are defined by their network layer IP addresses and their transport layer source and destination port numbers.

NetFlow technology has seen several generations that provide more sophistication in defining traffic flows, but "classic" NetFlow distinguished flows using a combination of seven key fields. Should one of these fields vary in value from another packet, the packets could be safely determined to be of different flows:

- Source IP address
- Destination IP address
- Source port number
- Destination port number

- Layer 3 protocol type
- Type of Service (ToS) marking
- Input logical interface

The first four of the fields NetFlow uses to identify a flow should be familiar. The source and destination IP addresses, plus the source and destination ports, identify the connection between source and destination application. The Layer 3 protocol type identifies the Layer 3 protocol header after the IP header. Also, the ToS byte in the IPv4 header holds information about how devices should apply quality of service (QoS) rules to the packets in that flow.

Configuring NetFlow

Configuring NetFlow on a router requires two separate configuration tasks:

1. Configuring the capture of data about flows, using the **ip flow** interface subcommand
2. Configuring details of how to send that data to the NetFlow collector, using the **ip flow-export** global command

First, to capture the flow data, the engineer needs to add **ip flow ingress** or **ip flow egress** commands to one or more interfaces. Both commands tell the router to capture NetFlow data for flows on the interface. The **ingress** option tells the router to monitor incoming packets on the interface, and the **egress** option tells the router to monitor outgoing packets on the interface. (A NetFlow flow is unidirectional, so one user connection to an application would exist as two NetFlow flows, one for each direction.)

To configure the collector, the router has several items to configure:

1. The NetFlow collector's IP address and UDP port number, on the **ip flow-export destination** *address port* global command
2. The version of NetFlow to follow when formatting the NetFlow records sent to the collector, with the **ip flow-export version** *version* global command
3. The source interface to use as the source of the packets sent to the collector, using the **ip flow-export source** *type number* global command

Example 19-6 shows a configuration based on the network shown in Figure 19-7. R1 collects data about flows on interface F0/0, both for ingress and egress packets. It then refers to the NetFlow collector at IP address 10.1.10.100, using UDP port 99. The configuration also defines the use of NetFlow Version 9 records and the use of a loopback interface for the source IP address of packets sent to the collector.

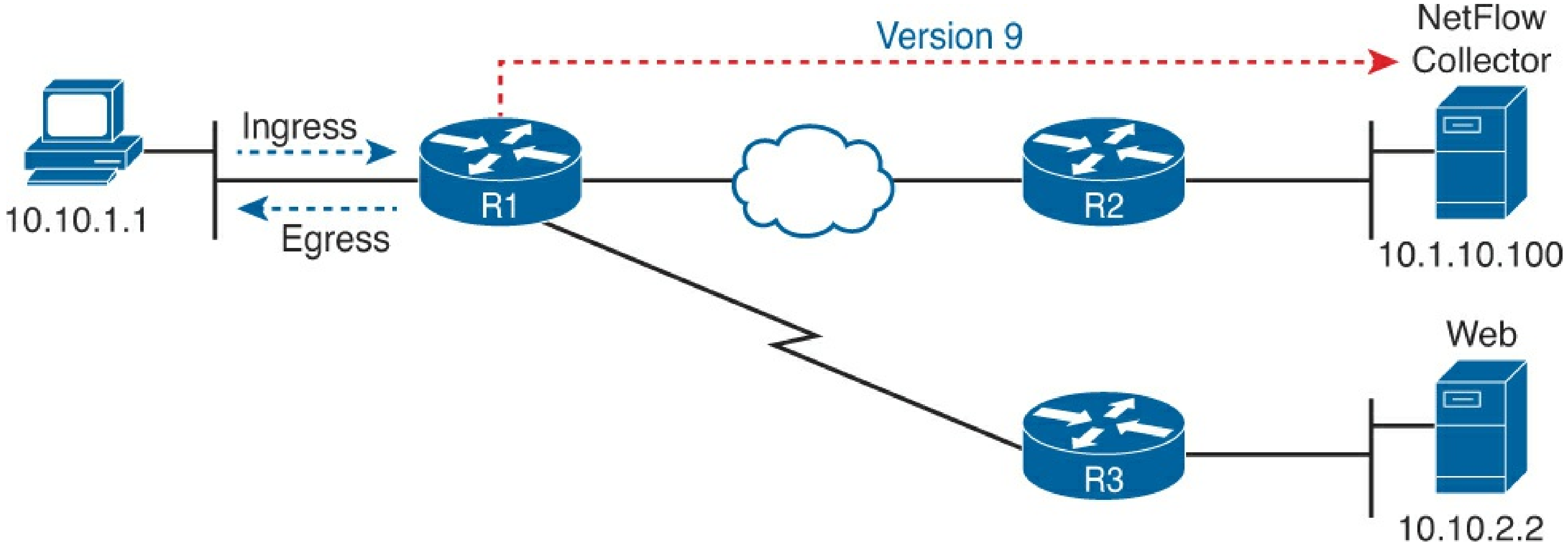


Figure 19-7. Network Used for NetFlow Configuration Example

Key Topic

Example 19-6. Configuring NetFlow on a Cisco Router

Click here to view code image

```
R1(config)# interface fastethernet0/0
R1(config-if)# ip flow ingress
R1(config-if)# ip flow egress
R1(config-if)# exit
R1(config)# ip flow-export destination 10.1.10.100 99
R1(config)# ip flow-export version 9
R1(config)# ip flow-export source loopback 0
R1(config)# end
```

```
R1#
```

Note

As mentioned earlier, NetFlow has been released in many different versions. Five formats are currently available, numbered 1, 5, 7, 8, and 9. The latest, Version, 9, is also known as Flexible NetFlow and is named so for the variety that is permitted when defining flows and record keeping for various parameters. Unfortunately, this version is not backward compatible with all versions of NetFlow.

Verifying and Using NetFlow

Once configured, you should verify NetFlow works, and then you can start using the collected data. The ultimate verification of NetFlow is to examine the information stored on the NetFlow collector itself, but you can also check the local NetFlow cache on a router directly, proving that the router is at least collecting the data. You do so with the **show ip cache flow** command shown in Example 19-7.

Example 19-7. Examining the NetFlow Cache

Click here to view code image

```
R1# show ip cache flow
IP packet size distribution (255 total packets):
1-32 64 96 128 160 192 224 256 288 320 352 384 416 448 480
.000 .000 .000 1.00 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000

512 544 576 1024 1536 2048 2560 3072 3584 4096 4608
.000 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000

IP Flow Switching Cache, 4456704 bytes
1 active, 65535 inactive, 1 added
32 ager polls, 0 flow alloc failures
Active flows timeout in 30 minutes
Inactive flows timeout in 15 seconds
IP Sub Flow Cache, 533256 bytes
1 active, 16383 inactive, 1 added, 1 added to flow
0 alloc failures, 0 force free
1 chunk, 1 chunk added
last clearing of statistics never
Protocol Total Flows Packets Bytes Packets Active(Sec) Idle(Sec)
-------- Flows Sec Flow /Pkt Sec Flow /Flow

SrcIf SrcIPaddress DstIf DstIPaddress Pr SrcP DstP Pkts
Fa0/0 10.10.1.1 S0/0/0 10.10.2.2 01 0200 0050 255
```

The output at the top of the command confirms that the router is indeed collecting data in the lab. The first highlighted entry lists a count of 255 packets monitored by NetFlow.

The bottom of the output shows statistics about the one flow created for this particular example. The example shows the results of PC1 connecting to a web server in Figure 19-7. The highlighted line shows the source IP address of 10.10.1.1, destination IP address of 10.10.2.2, and the total packets in this flow (255). It also shows the source port (SrcP) and destination port (DstP) in hexadecimal, which better identifies the flow; note that hex 50 is equal to decimal 80, the well-known TCP port for web services.

Although the data in Example 19-7 confirms that the router is collecting data, to ensure that you have NetFlow configured on the correct interfaces in the correct directions, you can use the command **show ip flow interface**, as shown in Example 19-8. Then, to check the configuration of your export parameters, you can use the command **show ip flow export**, also in the example. Note that the highlighted lines in the example track directly back to the configuration shown in Example 19-6.

Example 19-8. Confirming NetFlow Interface Configurations

Click here to view code image

```
R1# show ip flow interface
FastEthernet0/0
ip flow ingress
ip flow egress

R1# show ip flow export
Flow export v9 is enabled for main cache
```

```
Export source and destination details :
VRF ID : Default
Source(1) 1.1.1.1 (Loopback0)
Destination(1) 10.1.10.100 (99)
Version 9 flow records
0 flows exported in 0 udp datagrams
0 flows failed due to lack of export packet
0 export packets were sent up to process level
0 export packets were dropped due to no fib
0 export packets were dropped due to adjacency issues
0 export packets were dropped due to fragmentation fail ures
0 export packets were dropped due to encapsulation fixup failures
R1#
```

The NetFlow Collector

As described earlier, the NetFlow collector is a system running application software that is specialized for handling the raw NetFlow data. This system might be configured to receive the NetFlow information from many different systems in the infrastructure. Although viewing all of this raw data might make no sense to the human eye, the NetFlow collector software can aggregate and organize the information in a variety of ways to make perfect sense to network administrators. Custom reports serve to present the information in a variety of ways to different interested parties.

There are many different freeware and paid applications available for NetFlow collectors, but there are also reports that are typical across all applications. These reports often center on identifying the following:

- "Top talkers" in the network
- "Top listeners" in the network
- Most frequently visited websites
- Most frequently downloaded content
- Systems with the least available bandwidth

The amount of information that can be analyzed will vary based on the NetFlow version used. This is because the different versions define different NetFlow records. A NetFlow record contains the specific information about the actual traffic that makes up a NetFlow flow. For example, NetFlow Version 5 includes the following information in its records:

- Input interface index used by SNMP
- Output interface index
- Timestamps for flow start and finish
- Number of bytes and packets in flow
- Layer 3 headers
- TCP flags
- Layer 3 routing information including next hop

NetFlow Version 9 includes these fields and more, including Multiprotocol Label Switching (MPLS) labels and IPv6 addresses and ports.

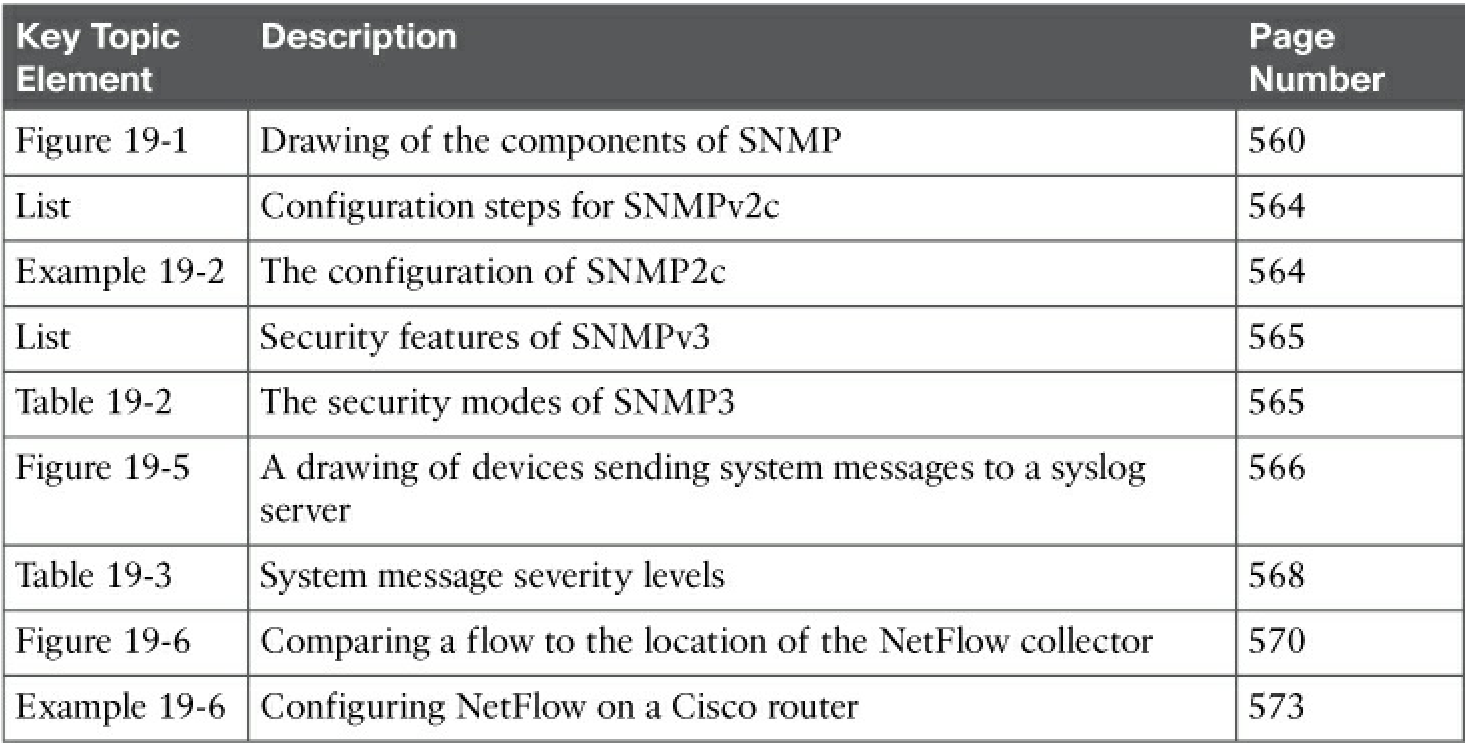
Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 19-4 lists these key topics and where each is discussed.

Key Topic

Table 19-4. Key Topics for Chapter 19



Key Topic Element	Description	Page Number
Figure 19-1	Drawing of the components of SNMP	560
List	Configuration steps for SNMPv2c	564
Example 19-2	The configuration of SNMP2c	564
List	Security features of SNMPv3	565
Table 19-2	The security modes of SNMP3	565
Figure 19-5	A drawing of devices sending system messages to a syslog server	566
Table 19-3	System message severity levels	568
Figure 19-6	Comparing a flow to the location of the NetFlow collector	570
Example 19-6	Configuring NetFlow on a Cisco router	573

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix D, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix E, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Definitions of Key Terms

After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22 directs you in how to use these terms for late-stage preparation for the exam.

SNMP
MIB
SNMP agent
NMS
Cisco Prime
GET message
SET message
trap
inform
OID
integrity
authentication
encryption
syslog
out-of-band
NetFlow

Chapter 20. Managing IOS Files

This chapter covers the following exam topics:

IP Routing Technologies

- Describe the boot process of Cisco IOS routers
    - POST
    - Router bootup process
- Manage Cisco IOS Files
    - Boot preferences
    - Cisco IOS image(s)

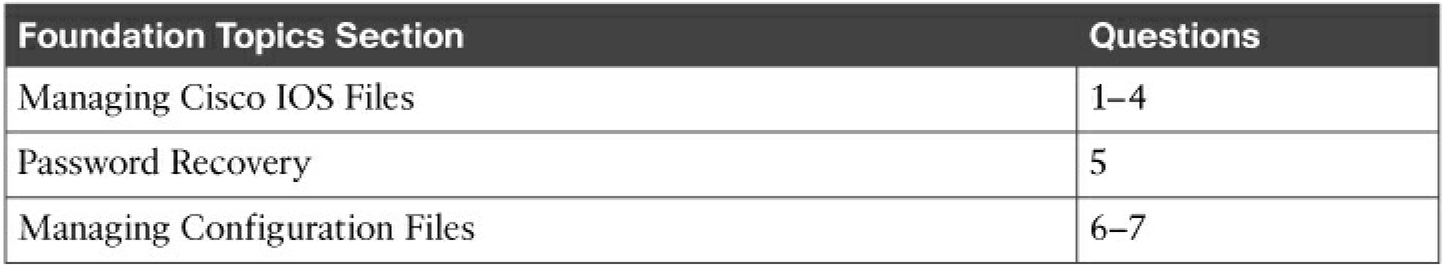
Network engineers also play a key role in managing the Cisco IOS devices themselves. That work includes managing the configuration files on the devices, keeping backup copies, and backing up and upgrading IOS software images.

This chapter explores three topics related to this vast subject of managing the boot process and image and configuration files of Cisco IOS devices. Although it is not exhaustive in its coverage, it does provide you with an excellent foundation to comprehend file management for many of Cisco's IOS-based routing and switching devices.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the "Exam Preparation Tasks" section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 20-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
Managing Cisco IOS Files	1–4
Password Recovery	5
Managing Configuration Files	6–7

1. What of these steps happens first during the router boot process?
    - **a.** The router locates the configuration file.
    - **b.** The POST.
    - **c.** The router locates the Cisco IOS image.
    - **d.** The router initiates the bootstrap code from ROM.
2. What is the first step a typical Cisco router takes, during the boot process, when attempting to locate an operating system to load?
    - **a.** The router looks for an image on a TFTP server.
    - **b.** The router checks its configuration register boot field.
    - **c.** The router boots to ROMMON.
    - **d.** The router looks in flash memory for an Cisco IOS image file.
3. After your Cisco router boots, what is a simple way to verify the Cisco IOS image that was loaded and the location from which it was copied into RAM?
    - **a. show running-config**
    - **b. show boot**
    - **c. show cisco ios**
    - **d. show version**
4. Which value in the configuration register controls how the router boots?
    - **a.** The third hexadecimal character
    - **b.** The second hexadecimal character
    - **c.** The first hexadecimal character
    - **d.** The last hexadecimal character
5. You have forgotten your privileged mode password and cannot access global configuration mode. During the password recovery process, how can you change the configuration register if you cannot remember enough passwords to get into configuration mode of the router?
    - **a.** Using ROMMON mode

b. Using the Setup Utility

c. Using the GUI for configuring the device

d. Using password reset mode

6. What type of router memory is used to store the configuration used by the router when it is up and working?

a. RAM

b. ROM

c. Flash

d. NVRAM

7. When a Cisco router boots using the image file located in flash, and this router does not have a startup-config file to load, how does the router respond?

a. The router enters ROMMON mode.

b. The router asks users if they want to start the Setup Utility.

c. The router does not load IOS.

d. The router prompts the user for the URL of the initial configuration file.

Answers to the "Do I Know This Already?" quiz:

1 B **2** B **3** D **4** D **5** A **6** A **7** B

Foundation Topics

Managing Cisco IOS Files

Cisco routers use Cisco IOS software as the operating system (OS) for the router. For the most part, this book and the ICND1 book ignore some of the details about working with the IOS as an end to itself. Instead, the books have discussed the networking functions of IOS a great deal. Now we turn our attention to basic device management issues, such as how to upgrade the IOS and how a router loads the IOS at power-on.

Unlike many other OSs you might have used, Cisco IOS exists as a single file called an *IOS image*. The software upgrade process includes steps such as copying a newer IOS image into flash memory, configuring the router to tell it which IOS image to use, and deleting the old IOS image when you are confident that the new release works well. The boot process on the router must be ready to pick the correct IOS image to use when the router powers on and, if that process fails for any reason, to have a way to overcome and fix the problem.

This first section of the chapter begins with a discussion of how to upgrade the Cisco IOS software on a router, followed by a discussion of the router boot process.

Note

This chapter focuses specifically on routers, not switches. However, many of the concepts apply to switches as well.

Upgrading a Cisco IOS Software Image into Flash Memory

Cisco routers do not usually have a disk drive. Instead, they use other types of memory for different purposes, as shown in Figure 20-1.

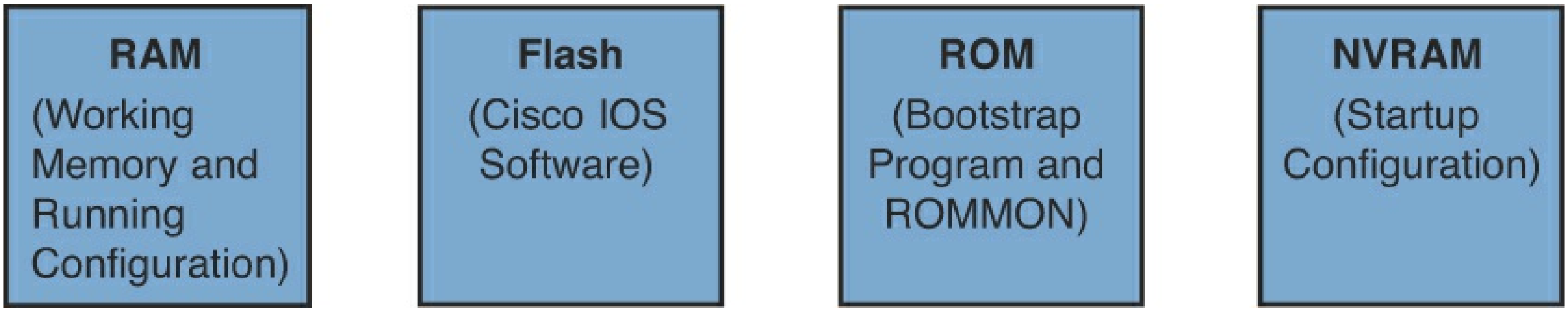

RAM
(Working Memory and Running Configuration)
Flash
(Cisco IOS Software)
ROM
(Bootstrap Program and ROMMON)
NVRAM
(Startup Configuration)

Figure 20-1. Types of Router Memory and Their Different Purposes

Routers usually store IOS images in flash memory. Flash memory is rewriteable, permanent storage, which is ideal for storing files that need to be retained when the router loses power. Cisco purposefully uses flash memory rather than disk drives in its products because there are no moving parts in flash memory, so there is a smaller chance of failure as compared with disk drives. Some models of routers use internal flash memory chips, whereas other use external flash memory slots that support flash memory cards commonly seen in consumer electronics. New routers also often support USB flash drives attached to an external USB port on the side of the router.

In addition, Cisco routers can store their IOS images on an external server, reachable over the network, usually using either TFTP or FTP protocols. However, using an external server typically is done for testing or for recovering from a problem with the IOS file in flash. In production, practically every Cisco router loads an IOS image stored in the only type of large permanent memory in a Cisco router: flash memory.

One of the first steps to upgrade a router's IOS to a new version is to obtain the new IOS image and put it in the right location, usually into flash memory on the router. Figure 20-2 illustrates the process to upgrade an IOS image into flash memory, using the steps in the following list:

Step 1. Obtain the IOS image from Cisco, usually by downloading the IOS image from Cisco.com using HTTP or FTP.

Step 2. Place the IOS image someplace that is reachable by the router. Locations include TFTP or FTP servers in the network or on a USB flash drive that is then inserted into the router.

Step 3. Issue the **copy** command from the router, copying the file into the flash memory that usually remains with the router on a permanent basis. (Routers usually cannot boot from the IOS image in a USB flash drive.)

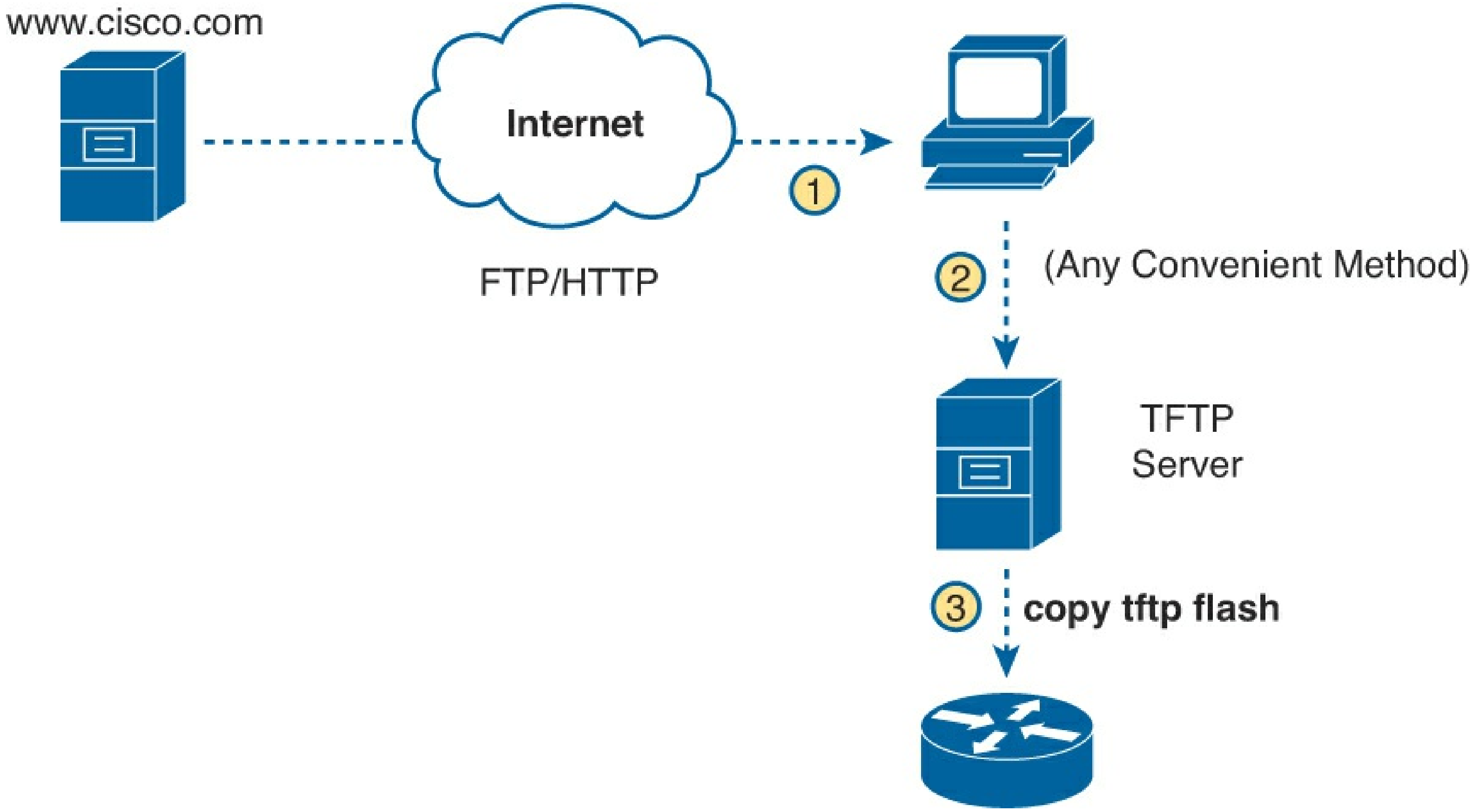


Figure 20-2. Copying IOS Image as Part of the Cisco IOS Software Upgrade Process

Example 20-1 provides an example of Step 3 from the figure, copying the IOS image into flash memory. In this case, router R2, a 2901, copies an IOS image from a TFTP server at IP address 2.2.2.1.

Example 20-1. copy tftp flash **Command Copies the IOS Image to Flash Memory**

Click here to view code image

```
R2# copy tftp flash
Address or name of remote host []? 2.2.2.1
Source filename []? c2900-universalk9-mz.SPA.152-4.M1.bin
Destination filename [c2900-universalk9-mz.SPA.152-4.M1.bin]?
Accessing tftp://2.2.2.1/c2900-universalk9-mz.SPA.152-4.M1.bin...
Loading c2900-universalk9-mz.SPA.152-4.M1.bin from 2.2.2.1 (via GigabitEthernet0/1):
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

```
[OK - 74503236 bytes]

74503236 bytes copied in 187.876 secs (396555 bytes/sec)
R2#
```

The **copy** command does a simple task—copy a file—but the command also has several small items to check. It needs a few pieces of information from the user, so the command prompts the user for that information, as shown in the bold items in the example. It then has to check to make sure the copy will work. The command works through these kinds of questions:

1. What is the IP address or host name of the TFTP server?
2. What is the name of the file?
3. Ask the server to learn the size of the file, and then check the local router's flash to ask whether enough space is available for this file in flash memory.
4. Does the server actually have a file by that name?
5. Do you want the router to erase any old files in flash?

The router prompts you for answers to some of these questions, as necessary. For each question, you should either type an answer or press **Enter** if the default answer (shown in square brackets at the end of the question) is acceptable. Afterward, the router erases flash memory if directed, copies the file, and then verifies that the checksum for the file shows that no errors occurred in transmission.

Once finished, you can then use the **show flash** command to verify the contents of flash memory, as demonstrated in Example 20-2. (The **show flash** output can vary among router families.)

Example 20-2. Verifying Flash Memory Contents with the show flash **Command**

Click here to view code image

```
R2# show flash
-#- --length-- -----date/time------ path
1 74503236 Feb 12 2013 19:06:54 +00:00 c2900-universalk9-mz.SPA.151-4.M4.bin
2 97794040 Sep 21 2012 14:02:50 +00:00 c2900-universalk9-mz.SPA.152-4.M1.bin


78909440 bytes available (172297280 bytes used)
```

Once the new IOS has been copied into flash, the router must be reloaded to use the new IOS image. For instance, in the output shown in Example 20-2, router R2 now has two IOS images in flash memory: the original Version 15.1(4) image and the newly copied Version 15.2(4) image. The next section, which covers the IOS boot sequence, explains the details of how to configure a router so that it loads the right IOS image, including how to tell the router to start using the new IOS image.

> **Note**
>
> The IOS image is usually a compressed file so that it consumes less space in flash memory. The router decompresses the IOS image as it is loaded into RAM.

The Cisco IOS Software Boot Sequence

Cisco routers perform the same types of tasks that a typical computer performs when you power it on or reboot (reload) it. However, most end-user computers have a single instance of the OS installed, so the computer does not have to choose which OS to load. In contrast, a router can have multiple IOS images available both in flash memory and on external TFTP servers, so the router needs a process by which to pick which IOS image to load into RAM and use. This section examines the entire boot process, with extra emphasis on the options that impact a router's choice of what IOS image to load.

> **Note**
>
> The boot sequence details in this section, particularly those regarding the configuration register and the ROMMON OS, differ from Cisco LAN switches, but they do apply to most every model of Cisco router. This book does not cover the equivalent options in Cisco switches.

When a router first powers on, it follows these four steps:

1. The router performs a power-on self-test (POST) process to discover the hardware components and verify that all components work properly.
2. The router copies a bootstrap program from ROM into RAM and runs the bootstrap program.
3. The bootstrap program decides which IOS image (or other OS) to load into RAM, and then the bootstrap program loads

the OS. After loading the other OS image, the bootstrap program hands over control of the router hardware to the newly loaded OS.

4. If the bootstrap program loaded IOS (instead of some other OS), IOS finds the configuration file (usually the startup-config file in NVRAM) and loads it into RAM as the running-config.

All routers attempt all four steps each time that the router is powered on or reloaded. The first two steps do not have any options to choose; these steps either work or the router initialization fails and you usually need to call the Cisco Technical Assistance Center (TAC) for support. However, Steps 3 and 4 have several configurable options that tell the router what to do next. Figure 20-3 depicts those options, referencing Steps 2 through 4 shown in the earlier boot process.

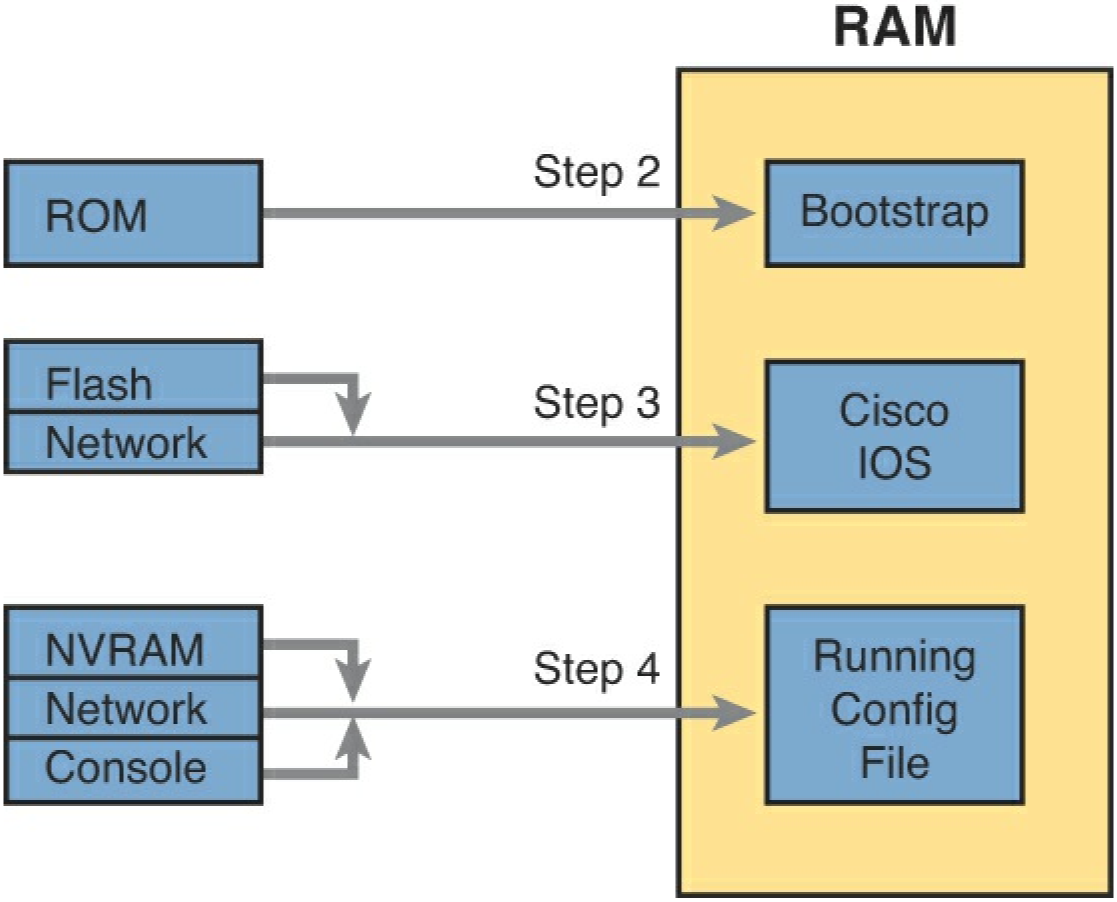


Figure 20-3. Loading the Bootstrap, IOS, and Initial Configuration

As you can see, the router has options at both Steps 3 and 4 in the figure. However, at Step 4, routers almost always load the configuration from NVRAM (the startup-config file), when it exists. There is no real advantage to storing the initial configuration anywhere else except NVRAM, so this chapter does not look further into the options of Step 4. But there are reasonable motivations for keeping IOS images in flash and on servers in the network, so the rest of this section examines Step 3 in more detail.

The next few pages discuss the router boot process and how a router chooses which IOS to load. But first you need to know a little more about some other OS options besides IOS and something about a tool used during the boot process: the configuration register.

The Three Router Operating Systems

A router usually loads and uses a Cisco IOS image. However, Cisco routers can use a different OS to perform some troubleshooting, to recover router passwords, and to copy new IOS files into flash when flash has been inadvertently erased or corrupted. Table 20-2 lists the other two router operating systems besides IOS and a few details about each.

Table 20-2. Comparing ROMMON and RxBoot Operating Systems

Operating Environment	Common Name	Stored In	Used In
ROM Monitor	ROMMON	ROM	Old and new routers
Boot ROM	RxBoot, boot helper	ROM	Only in older routers

Note that of these two other OSs besides IOS, the last few generations of Cisco routers have only used ROMMON and do not need nor support RxBoot. For that reason, this book ignores RxBoot, other than the brief mention in Table 20-2. However, ROMMON plays a key role in the password recovery process and some other actions when the router itself does not work correctly.

The Configuration Register

Next, you need some basic understanding of the idea of a Cisco router configuration register before discussing the boot process as well.

Routers use a configuration register to find some configuration settings at boot time, before the router has loaded IOS and read the startup-config file. The 16 bits (4 hex digits) in the configuration register set a variety of different parameters. For example, the console runs at a speed of 9600 bps by default, but that console speed is based on the default settings of a couple of bits in the configuration register. By changing specific bits in the configuration register, the next time the router boots, you can change the speed of the console line.

You can set the configuration register value with the **config-register** global configuration command. Engineers set the configuration register to different values for many reasons, but the most common are to help tell the router what IOS image to load, as explained in the next few pages, and in the password recovery process. For example, the command **config-register 0x2100** sets the value to hexadecimal 2100, which causes the router to load the ROMMON OS rather than IOS next time the router is reloaded.

Interestingly, Cisco routers automatically save the new configuration register value when you press **Enter** at the end of the **config-register** command; you do not need to use the **copy running-config startup-config** command after changing the configuration register. However, the configuration register's new value has no effect until the next time the router is reloaded.

> **Note**
>
> On most Cisco routers, the default configuration register setting is hexadecimal 2102, which leaves the console speed at 9600 bps, and tells the router to load an IOS image.

How a Router Chooses Which OS to Load

A router chooses the OS to load based on two factors:

- The last hex digit in the configuration register (called the boot field)
- Any **boot system** global configuration commands in the startup-config file

The boot field, the fourth hex digit in the configuration register, tells the router the initial instructions about what OS to try and load. The router looks at the boot field's value when the router is powered on or when reloaded. The boot field's value then tells the router how to proceed with choosing which OS to load.

> **Note**
>
> Cisco represents hexadecimal values by preceding the hex digits with 0x; for example, 0xA would mean a single hex digit A.

The process to choose which OS to load on more modern routers that do not have an RxBoot OS happens as follows:

Key Topic

1. If boot field = 0, use the ROMMON OS.
2. If boot field = 1, load the first IOS file found in flash memory.
3. If boot field = 2-F:
    A. Try each **boot system** command in the startup-config file, in order, until one works.
    B. If none of the **boot system** commands work, load the first IOS file found in flash memory.

> **Note**
>
> The actual step numbers are not important—the list is just numbered for easier reference.

The first two steps are pretty straightforward, but Step 3 then tells the router to look to the second major method to tell the router which IOS to load: the **boot system** global configuration command. This command can be configured multiple times on one router, with each new **boot system** command being added to the end of a list of **boot system** commands. Each command can point to different files in flash memory, and filenames and IP addresses of servers, telling the router where to look for an IOS image to load. The router tries to load the IOS images in the order of the configured **boot system** commands.

Both Step 2 and Step 3B refer to a concept of the "first" IOS file, a concept that needs a little more explanation. Routers number the files stored in flash memory, with each new file usually getting a higher and higher number. When a router tries Step 2 or Step 3B from the preceding list, the router looks in flash memory, starting with file number 1, and then file number 2, and so on, until it finds the lowest numbered file that happens to be an IOS image. The router then loads that file.

Interestingly, most routers end up using Step 3B to find their IOS image. From the factory, Cisco routers do not have any **boot system** commands configured; in fact, they do not have any configuration in the startup-config file at all. Cisco loads flash memory with a single IOS when it builds and tests the router, and the configuration register value is set to 0x2102, meaning a boot field of 0x2. With all these settings, the process tries Step 3 (because boot = 2), finds no **boot system** commands (because the startup-config is empty), and then looks for the first file in flash memory at Step 3B.

Figure 20-4 summarizes the key concepts behind how a router chooses the OS to load.

Key Topic

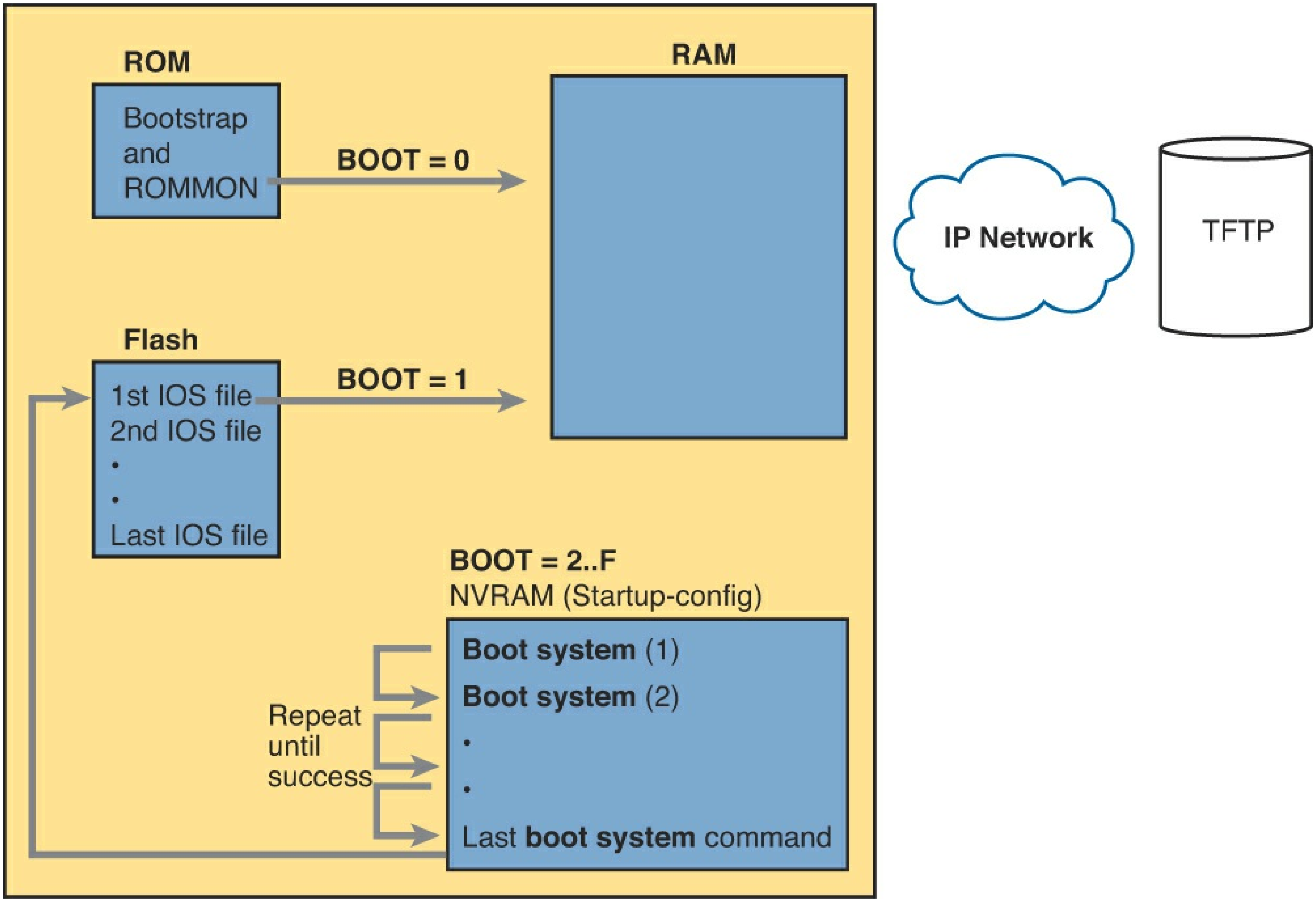
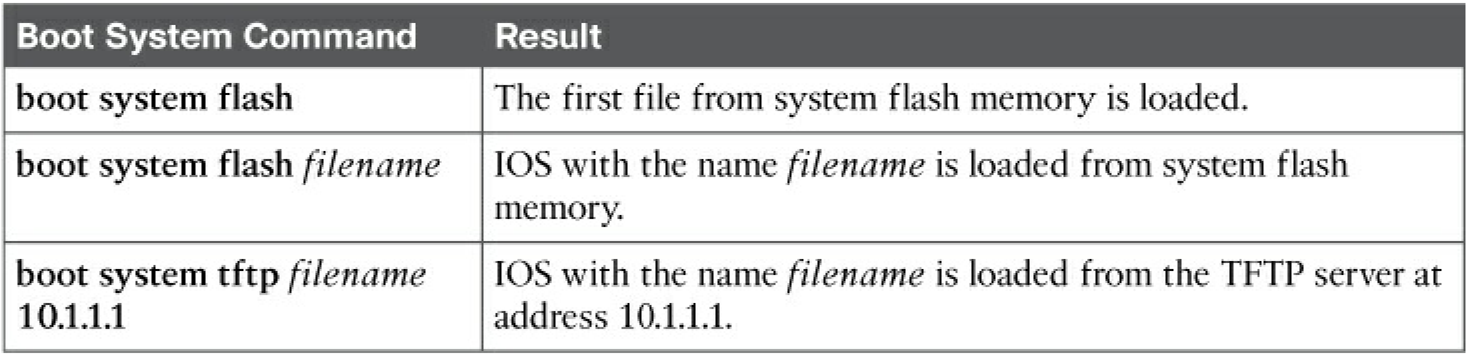

ROM
Bootstrap and ROMMON
BOOT = 0
RAM
IP Network
TFTP
Flash
1st IOS file
2nd IOS file
•
•
Last IOS file
BOOT = 1
BOOT = 2..F
NVRAM (Startup-config)
Boot system (1)
Boot system (2)
•
•
Last boot system command
Repeat until success

Figure 20-4. Choices for Choosing the OS at Boot Time: Modern Cisco Router

The **boot system** commands need to refer to the exact file that the router should load. Table 20-3 shows several examples of the commands.

Table 20-3. Sample boot system **Commands**



Boot System Command	Result
boot system flash	The first file from system flash memory is loaded.
boot system flash *filename*	IOS with the name *filename* is loaded from system flash memory.
boot system tftp *filename* 10.1.1.1	IOS with the name *filename* is loaded from the TFTP server at address 10.1.1.1.

Finally, remember the process of upgrading the IOS? Once a new IOS has been copied into flash memory on the router, the upgrade process has a few more steps. Add a **boot system** command to refer to the correct new file, save the configuration, and reload the router. The router will not go through the boot sequence discussed in this section, load the new IOS image, and the IOS upgrade is complete. For instance, Example 20-1 showed a router copying an IOS image into flash; that router would then also need a **boot system flash:c2900-universalk9-mz.SPA.152-4.M1.bin** command saved into the startup-config.

Recovering If the IOS Does Not Load

In some cases, a router fails to load IOS. For example, someone might accidentally erase all the contents of flash, including the IOS image. So, routers need more options to help recover from these unexpected but possible scenarios.

If an OS is not found by the end of Step 3, the router sends broadcasts looking for a TFTP server, guesses at a filename for the

IOS image, and loads an IOS image (assuming that a TFTP server is found). In practice, this process is highly unlikely to work. As a final attempt, the router loads ROMMON, which is the first step in the process to recover from these unexpected types of problems. For example, ROMMON provides enough function to copy a new IOS file into flash from a TFTP server to recover if someone has mistakenly erased the IOS image from flash memory.

Verifying the IOS Image Using the show version Command

The **show version** command supplies a wide variety of information about a router. In relation to IOS images, it not only lists the version of software, it lists the source from which the router found the IOS image, and the time since it loaded the IOS. As a result, the **show version** command actually identifies some key facts about the results of the previous boot process.

The **show version** command lists many other facts as well, as shown in Example 20-3. The example lists the **show version** command from router R2, the same router shown in Examples 20-1 and 20-2, in which a new IOS image was copied into flash. Since that time, R2 has added the **boot system flash:c2900-universalk9-mz.SPA.152-4.M1.bin** command and been reloaded, migrating to use the new Version 15.2(4) IOS.

To help point out some of the many important facts in this command, the example shows many highlighted items. The following list describes each of the items in the output in the same order as they are shown in the example, top to bottom:

Key Topic

1. The IOS version
2. The uptime (the length of time that has passed since the last reload)
3. The reason for the last reload of IOS (**reload** command, power off/on, software failure)
4. The time of the last loading of IOS (if the router’s clock has been set)
5. The source from which the router loaded the current IOS
6. The amount of RAM memory
7. The number and types of interfaces
8. The amount of NVRAM memory
9. The amount of flash memory
10. The configuration register’s current and future setting (if different)

Example 20-3. show version **Command Output**

Click here to view code image

```
R2# show version
Cisco IOS Software, C2900 Software (C2900-UNIVERSALK9-M), Version 15.2(4)M1, RELEASE SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2012 by Cisco Systems, Inc.
Compiled Thu 26-Jul-12 20:54 by prod_rel_team

ROM: System Bootstrap, Version 15.0(1r)M15, RELEASE SOFTWARE (fc1)

R2 uptime is 44 minutes
System returned to ROM by reload at 19:44:01 UTC Tue Feb 12 2013
System restarted at 19:45:53 UTC Tue Feb 12 2013
System image file is "flash:c2900-universalk9-mz.SPA.152-4.M1.bin"
Last reload type: Normal Reload
Last reload reason: Reload Command


This product contains cryptographic features and is subject to United
States and local country laws governing import, export, transfer and
use. Delivery of Cisco cryptographic products does not imply
third-party authority to import, export, distribute or use encryption.
Importers, exporters, distributors and users are responsible for
compliance with U.S. and local country laws. By using this product you
agree to comply with applicable laws and regulations. If you are unable
to comply with U.S. and local laws, return this product immediately.

A summary of U.S. laws governing Cisco cryptographic products may be found at:
http://www.cisco.com/wwl/export/crypto/tool/stqrg.html

If you require further assistance please contact us by sending email to
export@cisco.com.

Cisco CISCO2901/K9 (revision 1.0) with 483328K/40960K bytes of memory.
Processor board ID FTX1628837T
2 Gigabit Ethernet interfaces
4 Serial(sync/async) interfaces
1 terminal line
DRAM configuration is 64 bits wide with parity enabled.
255K bytes of non-volatile configuration memory.
3425968K bytes of USB Flash usbflash1 (Read/Write)
250880K bytes of ATA System CompactFlash 0 (Read/Write)


License Info:

License UDI:

-------------------------------------------------
Device# PID SN
-------------------------------------------------
*0 CISCO2901/K9 FTX1628837T



Technology Package License Information for Module:'c2900'

-----------------------------------------------------------------
Technology Technology-package Technology-package
Current Type Next reboot
------------------------------------------------------------------
ipbase ipbasek9 Permanent ipbasek9
security None None None
uc None None None
data None None None

Configuration register is 0x2102
```

Password Recovery

Suppose that you are sitting at your desk and you try to Secure Shell (SSH) or telnet to a router. However, you cannot log in. Or, you can get into user mode but not into enable mode because you forgot the enable secret password. You want to recover, or at least reset the passwords, so you can get into the router and change the configuration. What can you do?

Cisco gives us a way to reset the passwords on a router when sitting beside the router. With access to the router console, and the ability to power the router off and back on, anyone can reset all the passwords on the router to new values.

The details differ from router model to router model. However, if you go to www.cisco.com and search for “password recovery,” within the first few hits you should see a master password recovery page. This page lists instructions on how to perform password recovery (actually password reset) for almost any model of Cisco product.

> **Note**
>
> Cisco generally refers to the topic in this section as password recovery, but you do not actually recover and learn the password that you forgot. Instead, you change the password to a new value.

The General Ideas Behind Cisco Password Recovery/Reset

Although the details differ from model to model, all the password recovery procedures follow the same general principals. First, the end goal of the process is to make the router boot IOS while ignoring the startup-config file. Of course, this startup configuration holds all the passwords. Once the router boots while ignoring the initial configuration, you can log in at the console with no password restrictions and reconfigure all the passwords.

Cisco defines a specific configuration register bit that when set to binary 1 tells the router to ignore the startup-config file next time the router is loaded. To set that value, the default configuration register value of 0x2102 can be changed to 0x2142.

Unfortunately, you need to remember the enable password to reach the mode to configure the configuration register’s value. When you need to do password recovery, you clearly do not know the passwords, so how can you change the configuration register? The solution is to use ROMMON mode.

ROMMON lets you issue commands, including a command to set the configuration register. ROMMON contains a small and different set of CLI commands as compared to IOS. These commands even vary from router model to router model. However, each router’s ROMMON software supports some command, usually the **confreg** command, that lets you set the configuration register. For instance, the ROMMON command **confreg 0x2142** would set the correct bit to tell the router to ignore the startup-config file at reload.

So, how do you get the router to boot in ROMMON mode? Older routers support a traditional option, using a break key on the console, whereas newer routers may just require that the flash memory be removed, as follows:

- **Older routers:** Sit at the console and use a terminal emulator to type commands at the CLI. You turn the router off, and then power on again. Then, within the first 30 seconds, you press the “break” key on the keyboard. That tells the router to break the normal boot sequence and load ROMMON.
- **Newer routers (with all flash external):** Remove all flash memory cards. Turn off the router, and then power on again. The router fails to load an IOS, and instead loads ROMMON. (Put the flash back in once ROMMON loads.)

In summary, the big ideas behind password recovery are as follows:

Key Topic

Step 1. Boot ROMMON, either by breaking into the boot process from the console or by first removing all the flash memory.

Step 2. Set the configuration register to ignore the startup-config file (for example, confreg 0x2142).

Step 3. Boot the router with an IOS, and now you can reach enable mode from the console without needing any passwords.

A Specific Password Reset Example

Example 20-4 shows an example password recovery/reset process on a 2901 router. The example begins with router R1 powered on and the user connected at the console. 2901 routers have compact flash slots, as well as USB slots that support flash drives, so for this example, I removed the flash memory to make the router boot into ROMMON mode. R1 is powered-on to begin. Here are the steps in the example:

Step 1. Turn the router power switch off.

Step 2. Carefully remove compact flash from the router.

Step 3. Turn the router power switch on.

Step 4. Watch initialization messages, waiting for the ROMMON> prompt.

Step 5. Once the router is in ROMMON mode, with a ROMMON> prompt, carefully reinsert the compact flash.

Step 6. Set configuration register to 0x2142 using the ROMMON **confreg 0x2142** command.

Step 7. Issue ROMMON **reset** command, which makes the router work through its normal reload process (including using the new configuration register value).

Step 8. Watch for IOS to ask you to enter setup mode, because IOS should load, but with no initial configuration.

Step 9. Log in from the console (no passwords required) and move into enable mode. This gets past all password checks, but with no passwords required.

Step 10. Issue the **copy startup-config running-config** command to put all configuration back to its normal state so that the router begins doing its job again.

Step 11. Get into configuration mode and reset any forgotten passwords to new values.

Step 12. Issue the **copy running-config startup-config** command to save all the configuration, including changes to the passwords.

Step 13. Configure the configuration register back to its normal stable setting, usually 0x2102, so that the next time it reloads, the router does not load ROMMON again.

Example 20-4. An Example of Password Recovery/Reset

Click here to view code image

```
R1#! 1) User walks to the router and powers off the router

! 2) User removes all flash memory

! 3) User turns router back on again


System Bootstrap, Version 15.0(1r)M15, RELEASE SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 2011 by cisco Systems, Inc.

Total memory size = 512 MB - On-board = 512 MB, DIMM0 = 0 MB
CISCO2901/K9 platform with 524288 Kbytes of main memory
Main memory is configured to 72/-1(On-board/DIMM0) bit mode with ECC enabled

! 4) Several lines of messages omitted: ROMMON initializing

Readonly ROMMON initialized
rommon 1 > confreg 0x2142

You must reset or power cycle for new config to take effect
rommon 2 >
! 6) User walks to the router and plugs the flash back in.

rommon 3 > reset

System Bootstrap, Version 15.0(1r)M15, RELEASE SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 2011 by cisco Systems, Inc.

Total memory size = 512 MB - On-board = 512 MB, DIMM0 = 0 MB
CISCO2901/K9 platform with 524288 Kbytes of main memory
Main memory is configured to 72/-1(On-board/DIMM0) bit mode with ECC enabled

! Lots of IOS initialization messages omitted


--- System Configuration Dialog ---

Would you like to enter the initial configuration dialog? [yes/no]: no



Press RETURN to get started!

! 9) User logs in at the console and sets a new enable secret password.

Router>
Router>enable

! 10) User copies the starting config to make the router do its normal job
Router# copy startup-config running-config
Destination filename [running-config]?
```

```
3297 bytes copied in 0.492 secs (6701 bytes/sec)

! 11) User changes the forgotten enable secret password
R1# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R1(config)# enable secret cisco
R1(config)# ^Z
R1#

! 12) User saves his changes to the password
R1# copy running-config startup-config
Destination filename [startup-config]?
3297 bytes copied in 0.492 secs (6701 bytes/sec)

! 13) User changes the config register back to its normal 0x2102
R1# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R1(config)# config-reg 0x2102
R1(config)# ^Z
R1#
```

Note that those last few steps are pretty important. Remember, this process makes the router boot with no initial configuration, so it is clearly disruptive to the normal working state of the router, even beyond the time required to work through the process. The **copy startup-config running-config** command makes up for the fact that the router ignored the startup-config file when it booted IOS. Also, to be ready for the next time the router reloads, put the configuration register value back to its normal permanent value, usually hex 2102.

> **Note**
>
> When using this process, at the end, take the time to check the interface state of the router interfaces. The **copy running-config startup-config** command could result in some of the interfaces remaining in a shutdown state, depending on the current state of the cabling and the state of the connected devices. So, make sure to check and enable any interfaces with the **no shutdown** interface subcommand.

Managing Configuration Files

Cisco routers and switches happen to use two different configuration files: a startup-config file to save the configuration to use each time the device boots, and the running-config file that holds the currently used configuration for current use inside RAM.

This last of three major sections of the chapter reviews some key facts about these two configuration files. It also discusses the **copy** command and how you can use it to copy the contents of the configuration files. This section ends with a brief reminder of the setup process by which the router can build an initial configuration file.

Configuration File Basics

Cisco IOS stores the collection of configuration commands in a *configuration file*. In fact, routers use multiple configuration files: one file for the initial configuration used when powering on; and another configuration file for the active, currently used running configuration as stored in RAM. Table 20-4 lists the names of these two files, their purpose, and their storage location.

Key Topic

Table 20-4. Names and Purposes of the Two Main Cisco IOS Configuration Files

Configuration Filename	Purpose	Where It Is Stored
Startup-config	Stores the initial configuration used any time the switch reloads Cisco IOS.	NVRAM
Running-config	Stores the currently used configuration commands. This file changes dynamically when someone enters commands in configuration mode.	RAM

Essentially, when you use configuration mode, you change only the running-config file. If you want to keep that configuration, you have to issue the **copy running-config startup-config** command, overwriting the old startup-config file.

Example 20-5 demonstrates that commands used in configuration mode change only the running configuration in RAM. The example shows the following concepts and steps:

Step 1. The original **hostname** command on the router, with the startup-config file matching the running-config file.

Step 2. The **hostname** command changes the hostname, but only in the running-config file.

Step 3. The **show running-config** and **show startup-config** commands are shown, with only the **hostname** commands displayed for brevity, to make the point that the two configuration files are now different.

Example 20-5. Changing the Running-config File, But Not the Startup-config File

Click here to view code image

```
! Step 1 next (two commands)
!
hannah# show running-config
! (lines omitted)
hostname hannah
! (rest of lines omitted)

hannah# show startup-config
! (lines omitted)
hostname hannah
! (rest of lines omitted)

! Step 2 next. Notice that the command prompt changes immediately after
! the hostname command.
!
hannah# configure terminal
hannah(config)# hostname kris
kris(config)# exit

! Step 3 next (two commands)
!
kris# show running-config
! (lines omitted)
hostname kris
! (rest of lines omitted - notice that the running configuration reflects the
! changed hostname)

kris# show startup-config
! (lines omitted)
hostname hannah
! (rest of lines omitted - notice that the changed configuration is not
! shown in the startup config)
```

Copying and Erasing Configuration Files

If you reload the router at the end of Example 20-5, the hostname reverts to hannah because the running-config file has not been copied into the startup-config file. However, if you want to keep the new hostname of kris, you use the command **copy running-config startup-config**, which overwrites the current startup-config file with what is currently in the running configuration file.

You can use the IOS **copy** command to copy files in a router. The files can be any files at all, but most often the files are either IOS images or configuration files.

Other than copying the running-config to the startup-config to save changes, the most common use of the **copy** command for configuration files is to make a backup copy of the configuration. You can copy either the startup-config or running-config to a server or from the server back into the router, as shown in Figure 20-5.

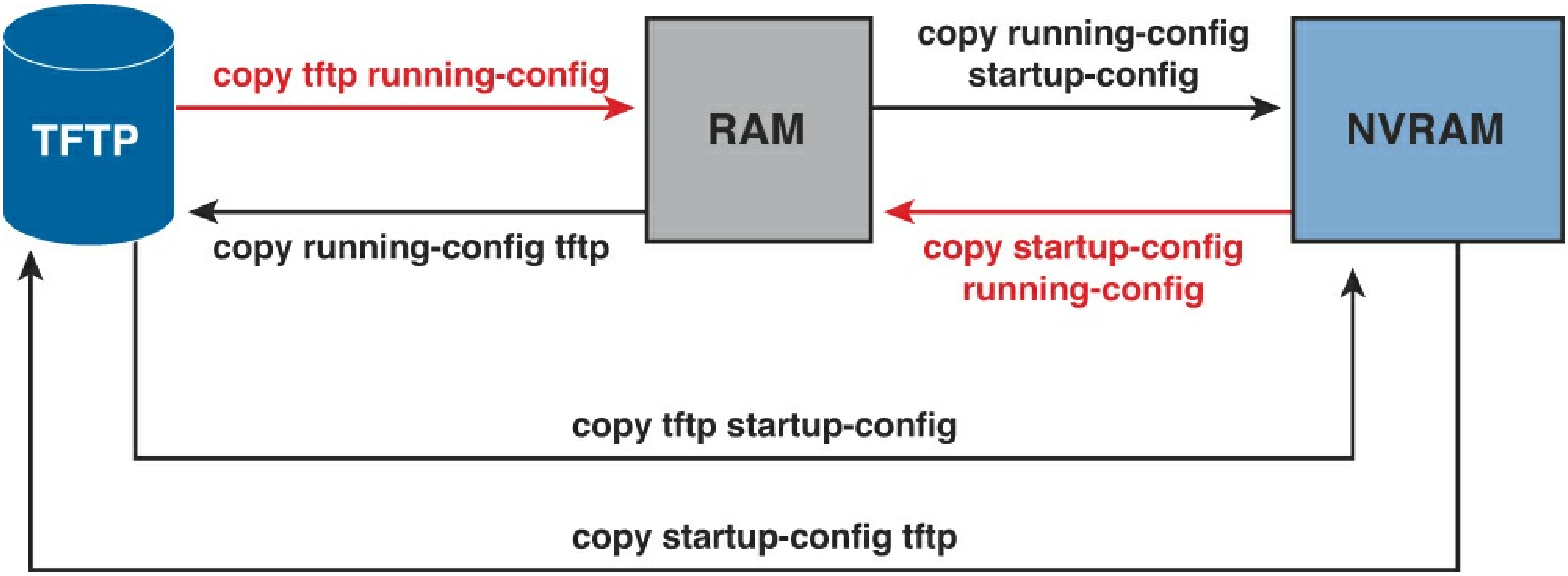


Figure 20-5. Locations for Copying and Results from Copy Operations

The commands for copying Cisco IOS configurations in the figure can be summarized as follows:

[Click here to view code image]

```
copy {tftp | running-config | startup-config} {tftp | running-config |
startup-config}
```

The first set of parameters enclosed in braces ({}) is the "from" location; the next set of parameters is the "to" location.

The **copy** command always replaces the existing file when the file is copied into NVRAM or into a TFTP server. In other words, it acts as if the destination file was erased and the new file completely replaced the old one. However, when the **copy** command copies a configuration file into the running-config file in RAM, the configuration file in RAM is not replaced, but is merged instead. Effectively, any **copy** into RAM works just as if you entered the commands in the "from" configuration file in the order listed in the config file.

Who cares? Well, we do. If you change the running config and then decide that you want to revert to what's in the startup-config file, the result of the **copy startup-config running-config** command might not cause the two files to actually match. The only way to guarantee that the two configuration files match is to issue the **reload** command, which reloads, or reboots, the router, which erases RAM and then copies the startup-config into RAM as part of the reload process.

Note

All of the Cisco IOS image and file management tasks, including the **copy** command, also support the IPv6. Therefore, if you have established IPv6 TFTP servers on your IPv6 network, these **copy** commands work perfectly with that new protocol suite.

When working with nearby routers in a lab, you might find it more convenient to copy files to and from removable flash memory in the router. The USB slots on most recent models of Cisco router allow you to insert and remove the USB flash drives with IOS running. For instance, a Cisco 2901 router has two USB flash drive slots (USBFlash0: and USBflash1:). As demonstrated in Example 20-6, an engineer could easily copy the running-config file to flash.

Example 20-6. Copying a File to USB Flash

[Click here to view code image]

```
R1# copy running-config usbflash1:temp-copy-of-config
Destination filename [temp-copy-of-config]?
3159 bytes copied in 0.944 secs (3346 bytes/sec)

R1# dir usbflash1:
Directory of usbflash1:/

1 -rw-4096 Feb 11 2013 17:17:00 +00:00 ._.Trashes
2 drw-0 Feb 11 2013 17:17:00 +00:00 .Trashes
7 drw-0 Feb 11 2013 17:17:00 +00:00 .Spotlight-V100
73 -rw-97794040 Feb 12 2013 21:49:36 +00:00 c2900-universalk9-mz.SPA.152-4.
M1.bin
74 -rw-3159 Feb 12 2013 22:17:00 +00:00 temp-copy-of-config

7783804928 bytes total (7685111808 bytes free)
R1#
```

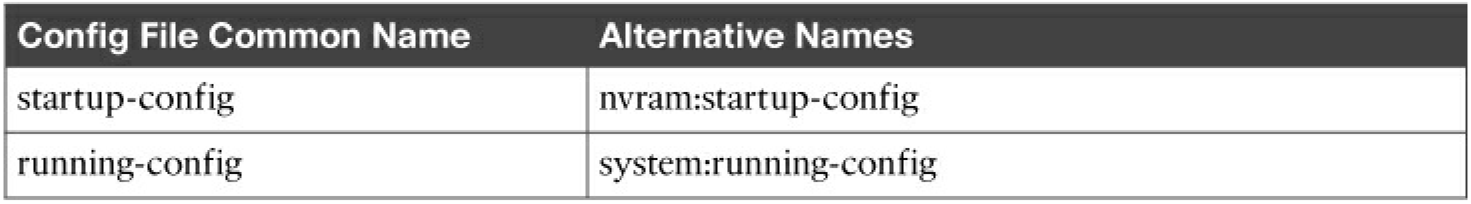
Besides copying files, you can also delete some files. For instance, IOS supports three different commands to erase the startup-config file in NVRAM. The **write erase** and **erase startup-config** commands are older, whereas the **erase nvram:** command is the more recent, and recommended, command.

Note that Cisco IOS does not have a command that erases the contents of the running-config file. To clear out the running-config file, simply erase the startup-config file, and then **reload** the router.

> **Note**
>
> Making a copy of all current router configurations should be part of any network's overall backup and security strategy. Keeping copies of the configuration lets you recover from mistakes or attacks that change the configuration.

Note one final thing about the names of the config files: Whereas most people use the common names *startup-config* and *running-config*, Cisco IOS defines a few other more formalized names for these files. These more formalized filenames use a format defined by the *Cisco IOS File System* (IFS), which is the name of the file system created by Cisco IOS to manage files. For example, the **copy** command can refer to the startup-config file as nvram:startup-config. Table 20-5 lists the alternative names for these two configuration files.

Table 20-5. IFS Filenames for the Startup and Running Config Files



Config File Common Name	Alternative Names
startup-config	nvram:startup-config
running-config	system:running-config

Initial Configuration (Setup Mode)

Cisco IOS software supports two primary methods of giving a switch an initial basic configuration: configuration mode and setup mode. Setup mode leads a switch administrator through a basic router configuration by using questions that prompt the administrator for basic configuration parameters. Because configuration mode is required for most configuration tasks, most networking personnel quickly get comfortable with configuration mode and do not use setup at all. However, new users sometimes like to use setup mode, particularly until they become more familiar with the CLI configuration mode.

Just so you know how to get to setup mode, an engineer can get into setup mode in two ways. Figure 20-6 shows one of the methods that occurs during the boot process: If the router boots, with no initial configuration, the router asks if the user wants to enter the "initial configuration dialogue," also known simply as setup mode. You can also enter setup mode by using the **setup** command from privileged mode.

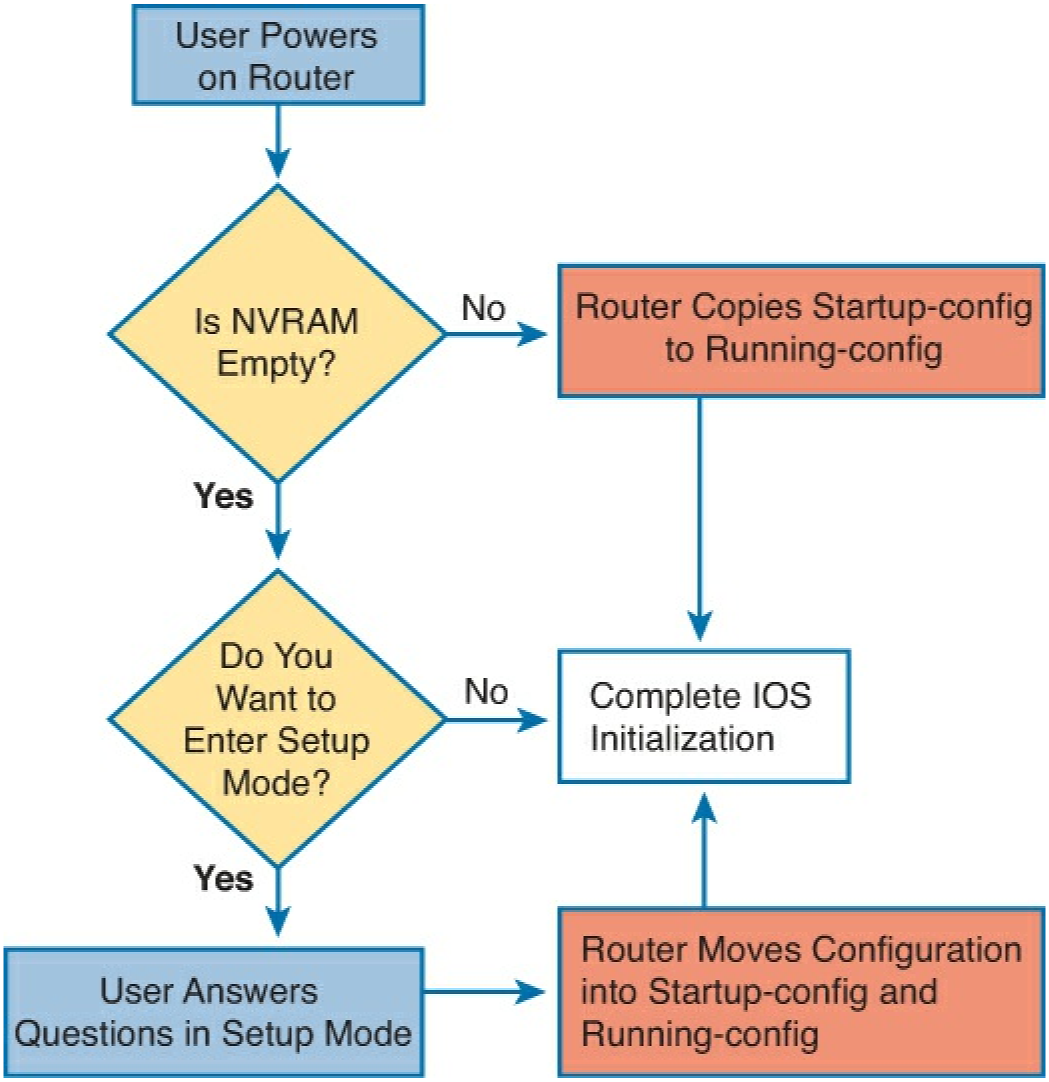

User Powers on Router
Is NVRAM Empty?
No
Router Copies Startup-config to Running-config
Yes
Do You Want to Enter Setup Mode?
No
Complete IOS Initialization
Yes
User Answers Questions in Setup Mode
Router Moves Configuration into Startup-config and Running-config

Figure 20-6. Logic and Decisions for Entering Setup Mode After Reload

Note

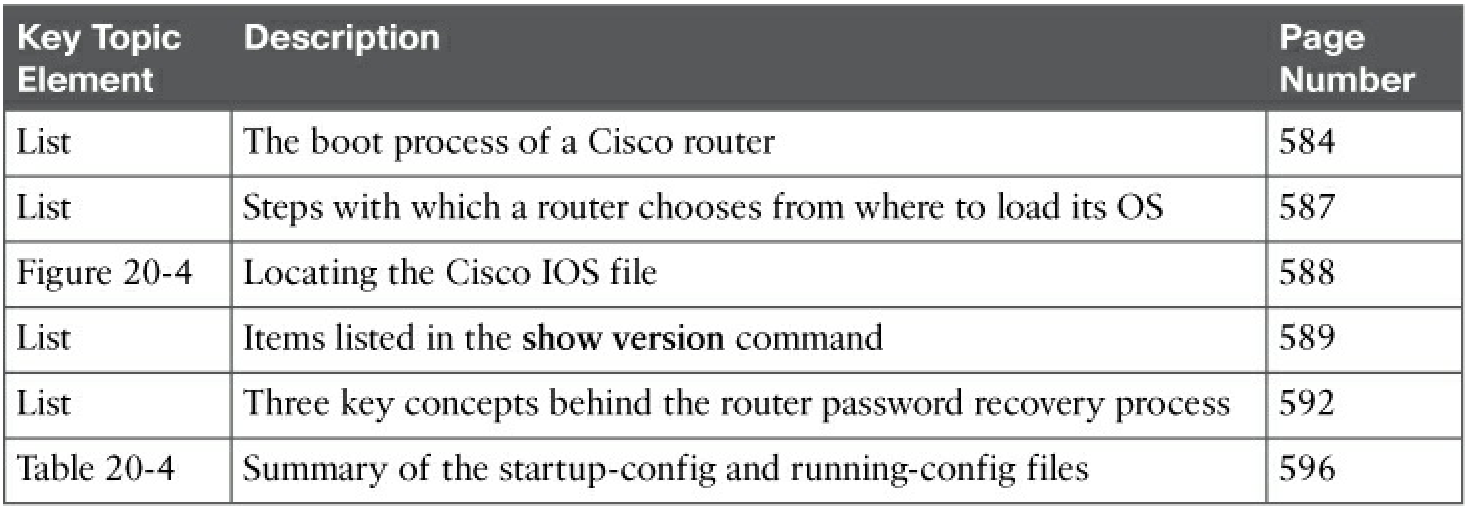
Example 20-3, earlier in this chapter, showed the password recovery process. That process caused a router to boot while ignoring the initial configuration, causing the router to ask the user the question shown in Figure 20-6.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 20-6 lists these key topics and where each is discussed.

Table 20-6. Key Topics for Chapter 20



Key Topic Element	Description	Page Number
List	The boot process of a Cisco router	584
List	Steps with which a router chooses from where to load its OS	587
Figure 20-4	Locating the Cisco IOS file	588
List	Items listed in the **show version** command	589
List	Three key concepts behind the router password recovery process	592
Table 20-4	Summary of the startup-config and running-config files	596

Definitions of Key Terms

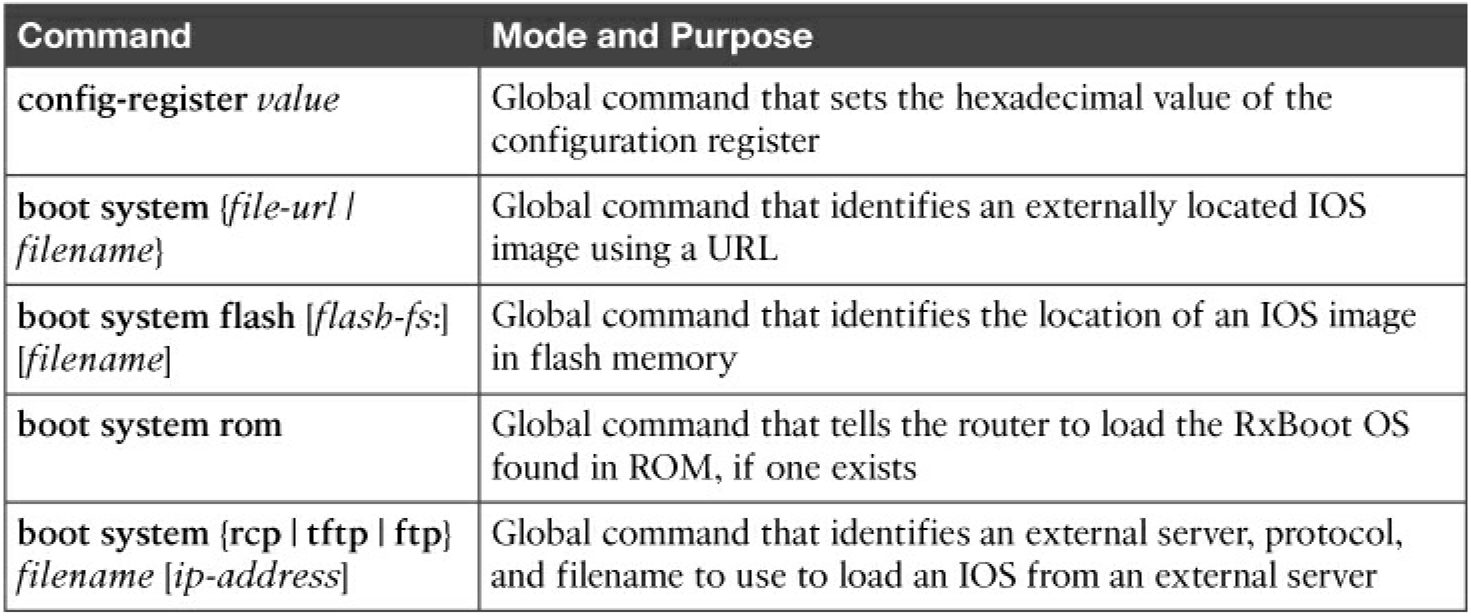
After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22 directs you in how to use these terms for late-stage preparation for the exam.

- boot field
- configuration register
- IOS image
- ROMMON
- startup-config file
- running-config file
- setup mode
- Internetwork Operating System (IOS)
- ROM
- flash memory
- NVRAM

Command References

Table 20-7 lists and briefly describes the configuration commands used in this chapter.

Table 20-7. Chapter 20 Configuration Commands



Command	Mode and Purpose
config-register *value*	Global command that sets the hexadecimal value of the configuration register
boot system {*file-url* | *filename*}	Global command that identifies an externally located IOS image using a URL
boot system flash [*flash-fs*:] [*filename*]	Global command that identifies the location of an IOS image in flash memory
boot system rom	Global command that tells the router to load the RxBoot OS found in ROM, if one exists
boot system {**rcp** | **tftp** | **ftp**} *filename* [*ip-address*]	Global command that identifies an external server, protocol, and filename to use to load an IOS from an external server

Table 20-8 lists and briefly describes the EXEC commands used in this chapter.

Table 20-8. Chapter 20 EXEC Command Reference

Command	Purpose
reload	Enable mode EXEC command that reboots the switch or router.
copy *from-location to-location*	Enable mode EXEC command that copies files from one file location to another. Locations include the startup-config and running-config files, files on TFTP and RPC servers, and flash memory.
copy running-config startup-config	Enable mode EXEC command that saves the active config, replacing the startup-config file used when the switch initializes.
copy startup-config running-config	Enable mode EXEC command that merges the startup-config file with the currently active config file in RAM.
show running-config	Lists the contents of the running-config file.
write erase **erase startup-config** **erase nvram:**	All three enable mode EXEC commands erase the startup-config file.
setup	Enable mode EXEC command that places the user in setup mode, in which Cisco IOS asks the user for input on simple switch configurations.
show flash	Lists the names and size of the files in flash memory, as well as noting the amount of flash memory consumed and available.

Chapter 21. Managing IOS Licensing

This chapter covers the following exam topics:

- **IP Routing Technologies**
- Manage Cisco IOS Files
- Licensing
  - Show license
  - Change license

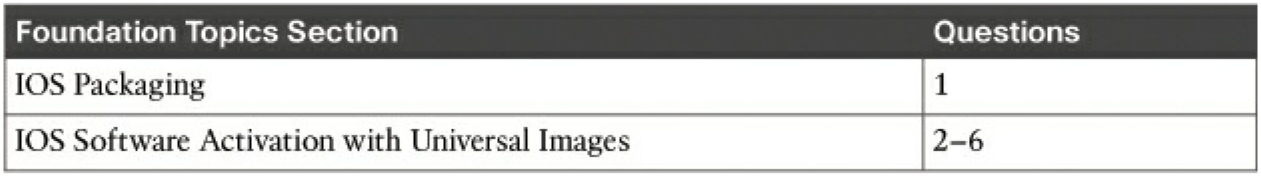
There have been major important changes in the way that Cisco creates software for its Cisco routers, and also major changes in how this software is licensed to individuals and organizations. In this chapter, we explore the past methods and detail the changes that have occurred.

This important chapter also guides you through the actual process of verifying your current licensing, installing a new license, activating license code, and even backing up and uninstalling licensing from a device.

"Do I Know This Already?" Quiz

Use the "Do I Know This Already?" quiz to help decide whether you might want to skim this chapter, or a major section, moving more quickly to the Exam Preparation Tasks section near the end of the chapter. You can find the answers at the bottom of the page following the quiz. For thorough explanations, see DVD Appendix C, "Answers to the 'Do I Know This Already?' Quizzes."

Table 21-1. "Do I Know This Already?" Foundation Topics Section-to-Question Mapping



Foundation Topics Section	Questions
IOS Packaging	1
IOS Software Activation with Universal Images	2–6

1. Imagine a Cisco router model X. Cisco produced IOS software for this model of router such that their customer could pay for baseline features, additional data features, additional voice features, and additional security features. With this traditional method of software production from Cisco, for a single IOS version, how many IOS images would be available for this one router model X?
   - **a.** 1
   - **b.** 2
   - **c.** 3
   - **d.** >3
2. What is the name of the new Cisco IOS image file that provides access to all major IOS features?
   - **a.** Universal
   - **b.** Full
   - **c.** Complete
   - **d.** Enhanced
3. What is the name of the license should you want to enable security features on your Cisco router?
   - **a.** Security
   - **b.** VPN
   - **c.** Securityk9
   - **d.** Encrypted
4. What command enables you to show the UDI of your Cisco router?
   - **a. show udi**
   - **b. show license udi**
   - **c. show base udi**
   - **d. show udi base**
5. Which of the following answers lists a CLI command on a router that is useful when installing a paid-for technology package license onto a 2901 router that uses Cisco IOS licensing and an IOS universal image?
   - **a. license boot module c2900 technology-package** *technology-package*
   - **b. license boot module technology-package** *technology-package* **install**
   - **c. license install** *url technology-package*
   - **d. license install** *url*
6. Which of the following answers lists a CLI command on a router that is useful when installing a right-to-use license onto a 2901 router that uses Cisco IOS licensing and an IOS universal image?

a. license boot module c2900 technology-package *technology-package*

b. license boot module technology-package *technology-package* **install**

c. license install *url technology-package*

d. license install *url*

Answers to the "Do I Know This Already?" quiz:

1 D **2** A **3** C **4** B **5** D **6** A

Foundation Topics

IOS Packaging

Cisco builds the Cisco Internetwork Operating System (IOS) software as a single file. Using a single file makes installation of a new IOS simple: You download the one file from Cisco, copy it to flash memory on the router, and then take steps to make sure the router boots the next time using the new IOS image. You learned the details of this process in Chapter 20, "Managing IOS Files."

Cisco continues to build the IOS as a single file today, but they have changed what they include in the IOS image files. This section looks at both the old and new methodologies for constructing images. This chapter also covers the new IOS licensing features that enable a router to use different parts of the IOS.

IOS Images per Model, Series, and per Software Version/Release

Since the early days of Cisco, back in the 1980s, through about the first 10 years of this century, Cisco created each IOS image for a particular router model, version and release, and feature set.

First, Cisco needed different IOS images for different router models, or at least for different router families, because of hardware differences. A low-end router with limited physical interfaces needed different software to support its interfaces than a high-end router that supported many different types of interface cards. Also, different router models often used different processors, so Cisco compiled different IOS images for use on those different processors.

Second, Cisco needed different IOS images for each new version or release of Cisco IOS software. Cisco identifies major revisions to Cisco IOS software using the term *version*, with smaller changes to IOS being called a *release*. However, Cisco did not use a model in which you install the IOS as one file, and then add bug fixes as separate files. Instead, to add a bug fix, to move to a new release, or to a new version, you had to get a whole new IOS file from Cisco, and then install and use the file on your routers. While this process is not necessarily difficult (as you learned in Chapter 20), it does provide administrative overhead as it needs to be planned for carefully.

Figure 21-1 shows a conceptual view of how Cisco ended up with many IOS images for each router. Routers had different IOS images for each router model or model series and, within each model series, different IOS files for each version of the software. For instance, the Cisco 2800 series had one set of IOS images for the 2801 router and another set for the other three routers in that series. For the 2801, for each new release, Cisco created and made available a whole new IOS file, posted for download at Cisco.com.

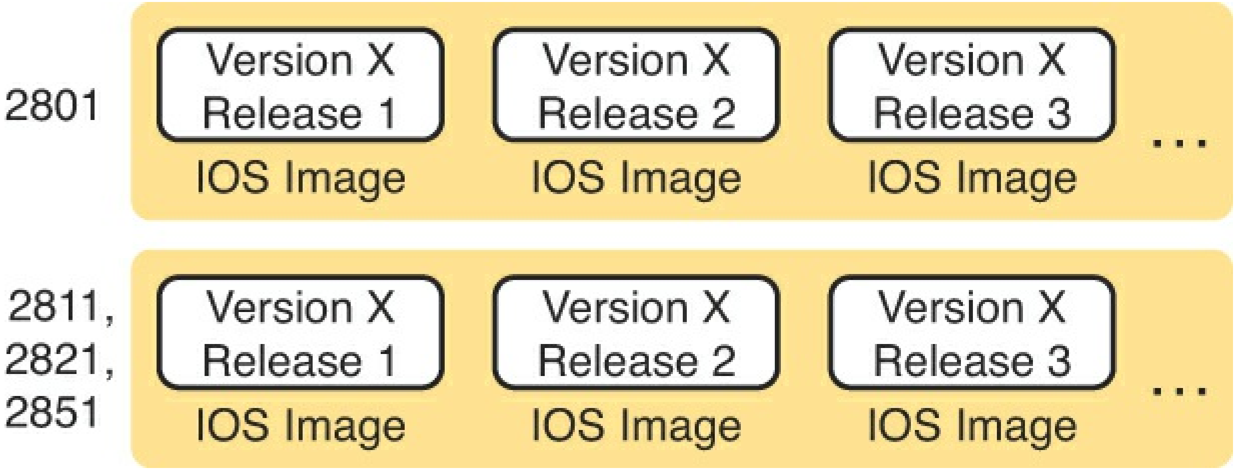


Figure 21-1. IOS Images per Model or Model Series, per Version/Release

Original Packaging: One IOS Image per Feature Set Combination

In addition, Cisco also created one image for each combination of IOS feature sets that was allowed on a router. A feature set is a group of related IOS features. For instance, voice features in a router would be in one feature set, while security features, like an intrusion prevention system (IPS), would be in a security feature set.

The feature set concept has a very basic business motivation: pricing. Customers who want fewer features want to pay less. Cisco desired more flexible pricing depending on the needs of a customer.

Using feature sets means that Cisco has to build even more IOS images. Not only did Cisco need one IOS image per model (or model series), per IOS version and even for each release, Cisco needed a different image per combination of feature sets.

To understand the point, Figure 21-2 shows a conceptual view of seven IOS images. Each is for the same model of router for the same software version/release. All the images have the same basic IP functions. Some have additional feature sets as well. And although the figure shows seven options to make the point, the number of combinations in the figure is far smaller than the real number of feature set combinations for a typical router model.

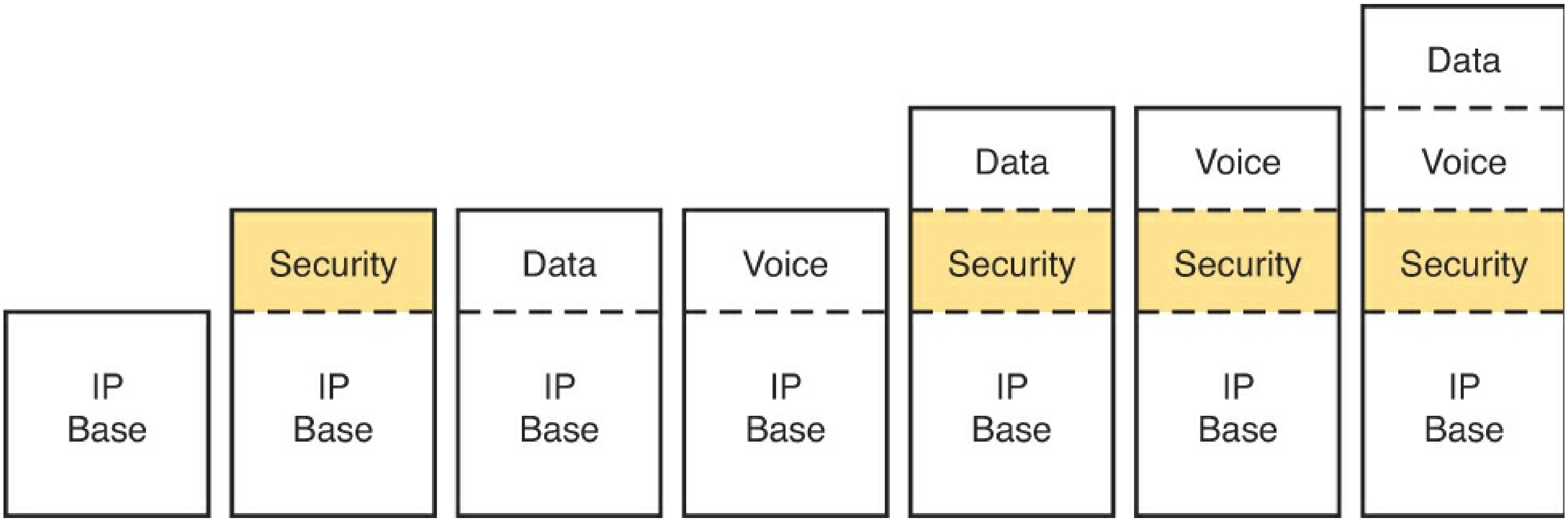


Figure 21-2. Old IOS Image Packaging: Different Images with Different Feature Sets

For example, suppose want to use a particular security feature that requires the Security feature set. You could choose to purchase any of the four IOS images with the highlighted Security feature set. If you did not want any advanced IP features, or voice features, you could avoid the IOS images on the right, which would be a little more expensive because of the number of feature sets included.

New IOS Packaging: One Universal Image with All Feature Sets

Cisco has begun using an IOS packaging model with a universal image. The term *universal image* means "all feature sets." Basically, instead of the old model of one image per feature set combination, as in Figure 21-2, Cisco builds one universal image with all feature sets. There would still be a different universal image per router model or model series, per version/release, just not a different image for different feature sets.

For example, if a router supported the IP Base features, plus Voice, Security, and an advanced IP feature set, Cisco would produce one universal image with all those features for each router model/series and for each version/release. Figure 21-3 shows an example of one image containing the IP Base, Security, Voice, Data, and Video features.

Key Topic

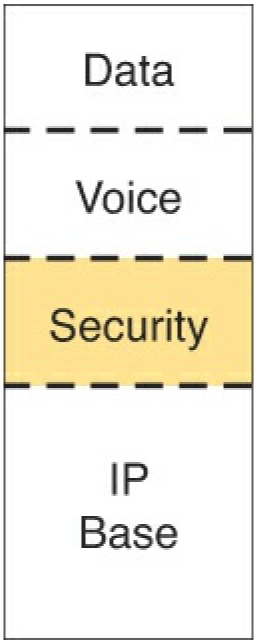


Figure 21-3. Universal Image: One Image Holds All Features

IOS Software Activation with Universal Images

Previously, Cisco permitted anyone to download any IOS image for any Cisco router. This download process required you to click that you agree with their terms of use. However, anyone could get the IOS images, and the images worked on real Cisco gear.

Cisco policies worked well for trustworthy customers, but as you would probably guess, it opened up the possibility of people misusing Cisco IOS software. For instance, companies could buy used Cisco hardware, download the latest Cisco IOS software, and use it—in spite of that usage breaking the Cisco terms of use and in spite of not having paid Cisco anything for the use of the software. Or, customers could choose avoid paying for the rights to download new versions of Cisco IOS versions, through a Cisco service agreement (often called SMARTnet), because the older system allowed most anyone to download newer software.

Around the time Cisco introduced the 1900, 2900, and 3900 series of Cisco routers—called Integrated Services Routers Generation 2, or ISR G2—Cisco made a couple of major changes to their software support process to help prevent theft. First, the software download area of the Cisco.com website now checks the user’s credentials. The user’s profile lists a company, and if that company has paid for a current service agreement that allows software downloads for a particular model of device, the user can indeed download the software. Otherwise, the Cisco download site rejects the attempt to download the software.

In addition, these newer routers, like ISR G2s, use universal IOS images with a software activation process. This idea is simple: To use the feature sets embedded in the universal image, you must unlock the feature set using a software activation process defined by Cisco. The universal image already has all the feature sets in it. The software activation process achieves two major goals:

Enable: It enables or activates the feature on the router. Without software activation, the feature does not work, and the related commands are not recognized by the CLI.

Verifies legal rights: It checks and confirms that the Cisco customer has paid for the right to use that feature set on that router.

For instance, a customer could buy a 2901 router, an ISR G2 router model that uses a universal image and the Cisco software activation process. All such routers come with the most basic feature set (IP Base) enabled already, with a license key for that feature already installed on the router. Later, the customer could choose to use software activation to enable the Security feature set—a process that requires the installation of a license key for the Security feature set, as shown in Figure 21-4.

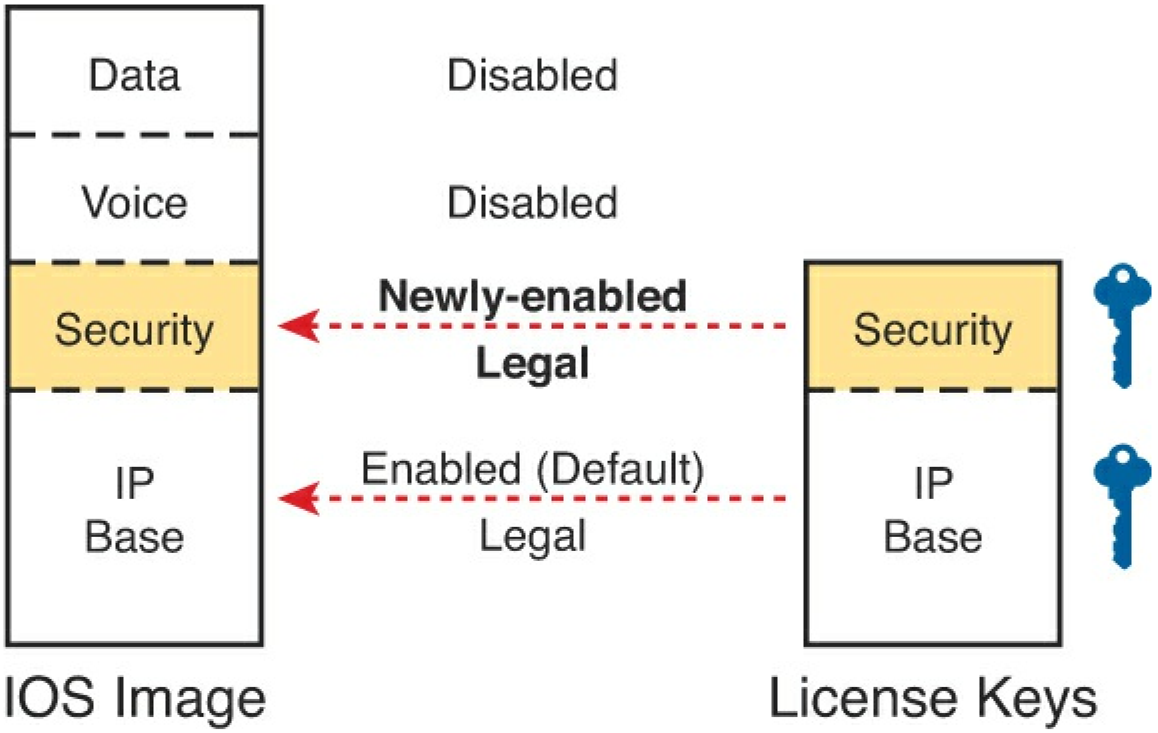
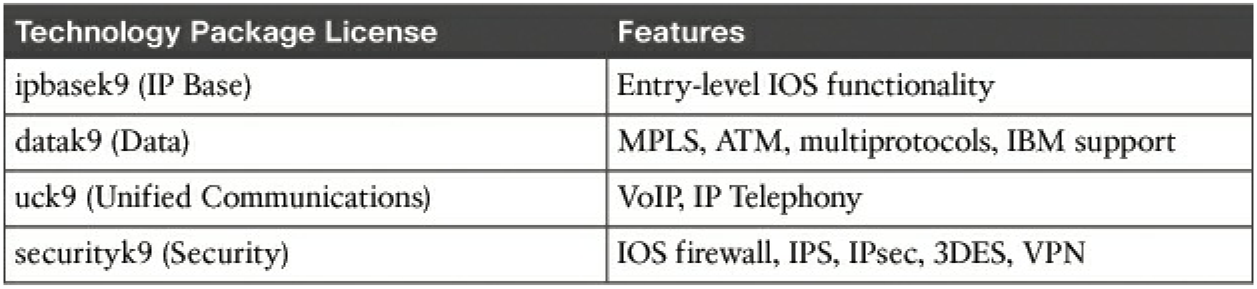


Figure 21-4. License Keys Inside a Router That Enable IOS Features

Cisco has a variety of different types of features and licenses that can be enabled. Cisco calls the feature sets with the most significant set of features technology packages. Table 21-2 provides the technology package licenses that are available on the Cisco ISR G2 platforms of the 1900, 2900, and 3900 series routers.

Key Topic

Table 21-2. Some Technology Package Licenses



Technology Package License	Features
ipbasek9 (IP Base)	Entry-level IOS functionality
datak9 (Data)	MPLS, ATM, multiprotocols, IBM support
uck9 (Unified Communications)	VoIP, IP Telephony
securityk9 (Security)	IOS firewall, IPS, IPsec, 3DES, VPN

Note

The IP Base license is a prerequisite for installing the Security, Data, and Unified Communications licenses.

Managing Software Activation with Cisco License Manager

Cisco customers can purchase the features when ordering the router or add them later. If purchased when ordering the router, Cisco adds the licenses to the router at the factory, and the customer has no additional work to add licenses. Alternatively, the customer can later purchase a license for a feature set and then follow the software activation process to enable that feature set on the router.

Most larger companies will likely manage Cisco licenses using an application called the Cisco License Manager (CLM). This free software package can be installed on many Windows client and server operating systems, as well as on Sun Solaris and Red Hat Linux. The CLM:

- Communicates with Cisco's Product License Registration Portal over the Internet
- Takes as input information about feature licenses purchased from any Cisco reseller
- Communicates with the company's routers and switches to install license keys, enabling features on the correct devices

Figure 21-5 shows the central location of CLM in the Cisco licensing process.

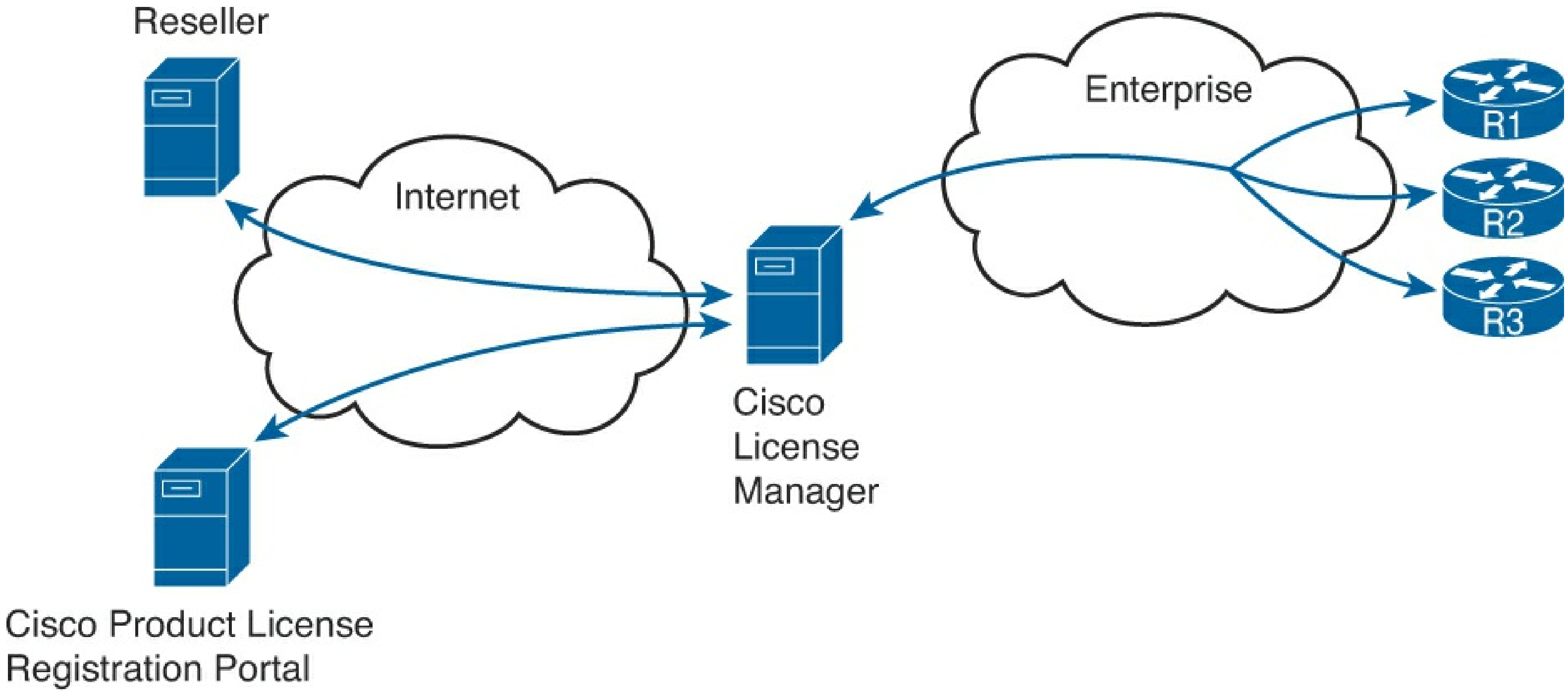


Figure 21-5. Location of Cisco License Manager in Software Activation

If you use CLM, you only need to know the big ideas of what needs to be done with licensing, while ignoring many details of how licensing happens. Instead, CLM tracks the information. You can purchase the licenses from any Cisco reseller. The application lets you see what you have purchased and see the licenses that have already been assigned for use on specific devices. You can also choose specific devices to receive new rights to use new feature sets and enable those features through an easy-to-use graphical user interface.

Manually Activating Software Using Licenses

CLM gives you an easier way to manage the entire Cisco software activation process, but you can also use a completely manual process. The manual process requires you to web browse to the Cisco Product License Registration Portal (a part of the Cisco.com website) and do some CLI commands on your router. Plus, you must follow a multistep process to put all the pieces together. Basically, you do all the work that CLM does for you. This next topic looks at the cleanest version of the process, without going into any of the options.

First, each of the same router model that supports software licensing has a unique identifying number named the *unique device identifier* (UDI). The UDI has two main components: the product ID (PID) and the serial number (SN). The following example shows the output from the **show license udi** command. In Example 21-1, you can clearly see the product ID, serial number, and UDI of the router.

Example 21-1. Examining the UDI on a Cisco Router

Click here to view code image

```
R1# show license udi
Device# PID SN UDI
-----------------------------------------------------------------------------
*0 CISCO2901/K9 FTX162883H0 CISCO2901/K9:FTX162883H0
```

Next, the process requires proof that you paid for a license to use a particular feature on a particular model of router. The real world uses paper receipts to show that you bought something at a store; for software feature sets, the receipt is called a product authorization key, or PAK. The PAK acts as a receipt, plus it has another unique number on it, which Cisco can find in a database to confirm what feature set license you actually bought.

The next step connects the license, which you can use on any router of that same model, to a specific router. To do so, you walk through a process that marries the PAK (the generic rights to a license) to the UDI (that identifies a specific router) to create a license key. To do so, you open a web browser and copy the PAK and UDI numbers onto a web page at the Cisco Product License Registration Portal. Cisco checks out the details: that the UDI is for a real router, that the PAK is real, that you have not already used that one PAK to enable this feature on another router, and any other checks to prevent fraud. If it all checks out, Cisco emails you with the license key file attached (also available for download).

Figure 21-6 summarizes these first three steps, with Figure 21-7 showing the later steps:

Step 1. At the Cisco Product License Registration Portal (reachable from www.cisco.com/go/license), input the UDI of the router, as gathered using the **show license udi** command.

Step 2. At that same portal, type in the PAK for the license you purchased, as learned from your reseller or directly from Cisco.

Step 3. Copy the license key file (download or email) when prompted at Cisco's Product License Registration Portal website.

Key Topic

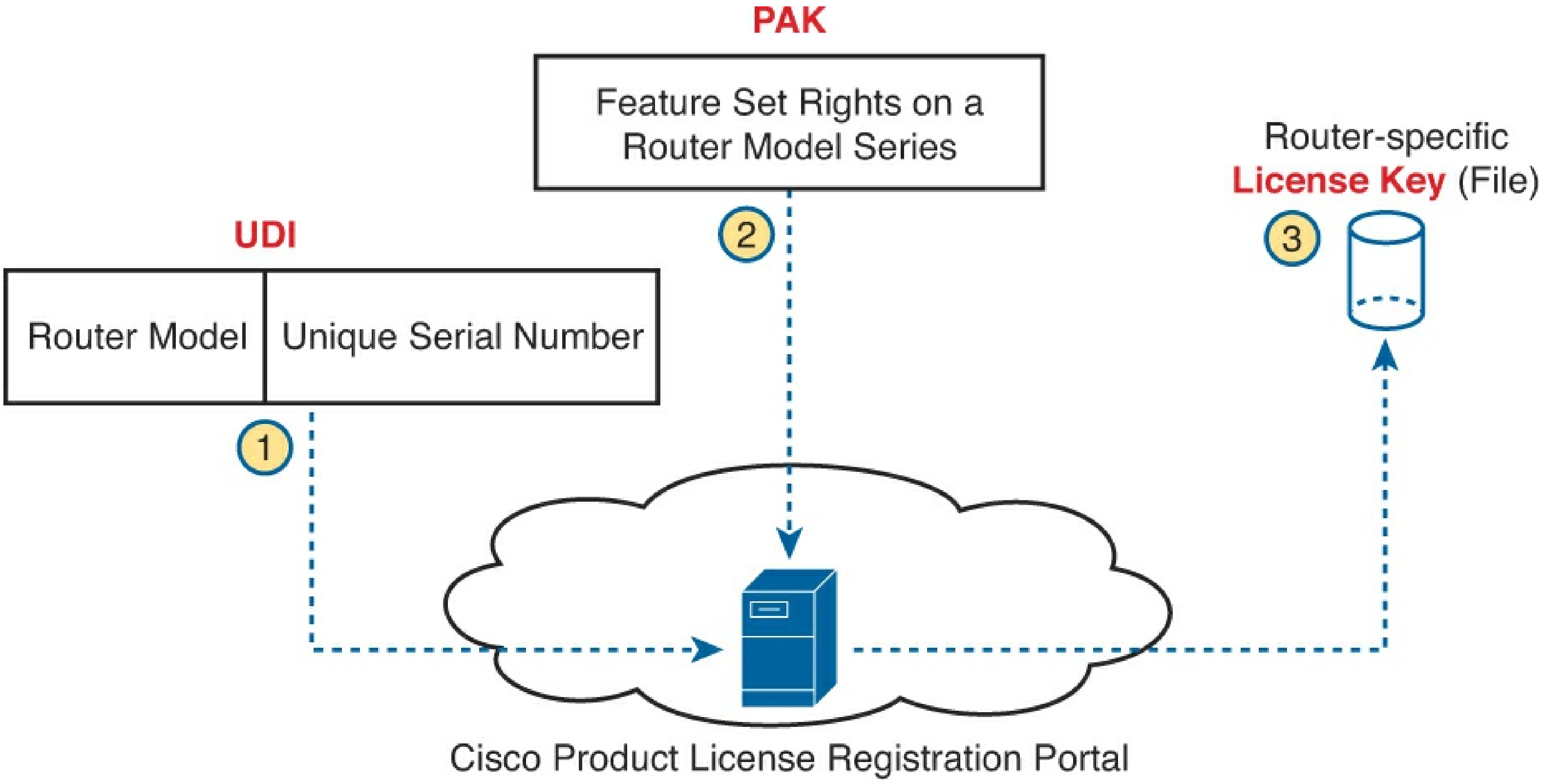

PAK
Feature Set Rights on a Router Model Series
Router-specific License Key (File)
UDI
Router Model
Unique Serial Number
1
2
3
Cisco Product License Registration Portal

Figure 21-6. PAK and UDI Needed to Get Unique License Key File from Cisco.com

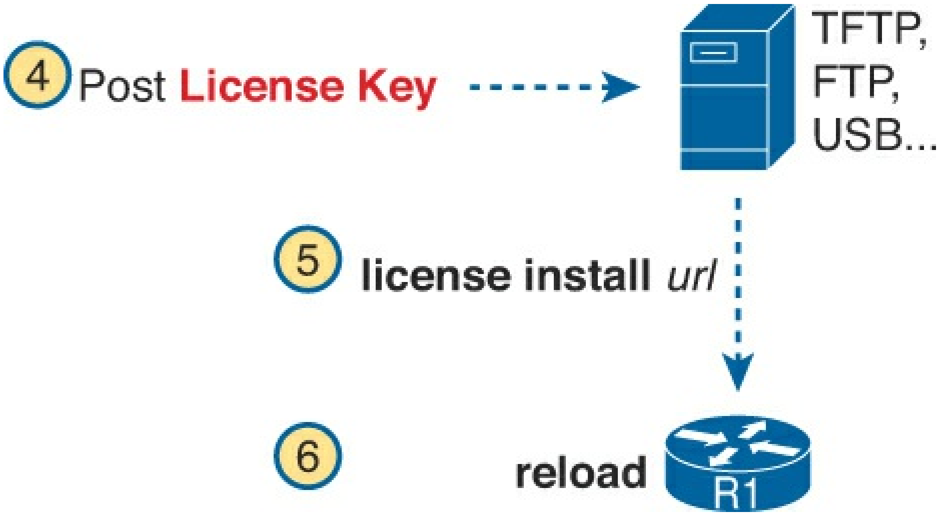

4
Post License Key
TFTP,
FTP,
USB...
5
license install url
6
reload
R1

Figure 21-7. Copying and Installing the License on a Router

> **Note**
>
> As of the time of this writing, the landing page for the Cisco Product License Registration Portal (www.cisco.com/go/license) included videos about how to do the steps in Figure 21-6 plus the rest of the process of how to work with Cisco licenses. The videos call the process in Steps 1 and 2 "fulfilling a PAK."

After the three steps shown in Figure 21-6, the router still does not have the feature set enabled. At this point, the license key exists as a file after Step 3. That license key unlocks that one feature set on one router: the router whose UDI was used to create the key. The rest of the process enables the license on that one router, by moving the license key file into that one router and reloading the router.

The next step can use any supported method to make the license key file available to the router, with a couple of commands to follow. In a lab, the simplest way is to just copy the file to a USB flash drive and move the flash drive to the router's USB slot. For remote routers, just copy the file to a known TFTP, FTP, or HTTP server. The steps, picking up with Step 4 as a continuation of the previous list, are as follows:

Step 4. Make the file available to the router via USB or some network server.

Step 5. From the router CLI, issue the **license install** *url* command to install the license key file into the router. (The URL points to the file.)

Step 6. Reload the router to pick up the changes.

Figure 21-7 shows these next three steps.

Example of Manually Activating a License

To bring the concept from the general to the specific, the next few pages show an example of the installation of a Data license on a model 2901 router. The example begins by showing the current state of the licenses in a sample router, and then shows how to change the licenses.

Showing the Current License Status

The example begins with Router R1, with only the IP Base feature enabled. No other licenses have been enabled on this router. Example 21-2 shows the status of the available features, with the enabled IP Base highlighted and the three technology package licenses highlighted, as well: Security, Voice, and Data.

Example 21-2. Initial License Status on Router R1

Click here to view code image

```
R1# show license
Index 1 Feature: ipbasek9
Period left: Life time
License Type: Permanent
License State: Active, In Use
License Count: Non-Counted
License Priority: Medium
Index 2 Feature: securityk9
Period left: Not Activated
Period Used: 0 minute 0 second
License Type: EvalRightToUse
License State: Not in Use, EULA not accepted
License Count: Non-Counted
License Priority: None
Index 3 Feature: uck9
Period left: Not Activated
Period Used: 0 minute 0 second
License Type: EvalRightToUse
License State: Not in Use, EULA not accepted
License Count: Non-Counted
License Priority: None
Index 4 Feature: datak9
Period left: Not Activated
Period Used: 0 minute 0 second
License Type: Permanent
License State: Active, Not in Use
License Count: Non-Counted
License Priority: Medium
! Lines omitted for brevity; 8 more feature licenses available
```

The highlighted lines spell out the current state. The first highlight refers to the IP Base feature set, with an unlimited lifetime. (Note that Cisco enables the IP Base feature set on all routers, with the other feature sets being optional upgrades.) The next three highlighted sections list the Security, Voice (Unified Communications, or UC), and Data licenses, respectively, all listed as Not Activated. Also, note that the output of the **show license** command on a 2901 includes several additional feature licenses omitted from the example for the sake of space.

The **show license** command shows several lines of status information per feature, but as shown in Example 21-3, the **show version** and **show license feature** commands list shorter status information. The **show license feature** command lists one line of output, with the Enabled column on the right showing the current status. The **show version** command lists license information for the main technology feature packages at the end of the output.

Example 21-3. Initial License Status on Router R1

Click here to view code image

```
R1# show license feature

Feature name Enforcement Evaluation Subscription Enabled RightToUse
```

```
ipbasek9 no no no yes no
securityk9 yes yes no no yes
uck9 yes yes no no yes
datak9 yes yes no no yes
gatekeeper yes yes no no yes
SSL_VPN yes yes no no yes
ios-ips-update yes yes yes no yes
SNASw yes yes no no yes
hseck9 yes no no no no
cme-srst yes yes no no yes
WAAS_Express yes yes no no yes
UCVideo yes yes no no yes

R1# show version
Cisco IOS Software, C2900 Software (C2900-UNIVERSALK9-M), Version 15.1(4)M4, RELEASE SOFTWARE (fc1)

! Lines omitted for brevity

License UDI:
-------------------------------------------------

Device# PID SN
-------------------------------------------------
*0 CISCO2901/K9 FTX1628838P


Technology Package License Information for Module:'c2900'

-----------------------------------------------------------------
Tecnology Technology-package Technology-package
Current Type Next reboot
------------------------------------------------------------------
ipbase ipbasek9 Permanent ipbasek9
security None None None
uc None None None
data None None None

Configuration register is 0x2102
```

Adding a Permanent Technology Package License

Next, Example 21-4 shows the engineer installing the license on router R1 for the Data feature set. The engineer has already followed the steps to get the license file from the Cisco Product License Registration Portal, with the file placed onto a USB drive and plugged into R1. That is, from Figures 21-6 and 21-7, the engineer has completed Steps 1 through 4.

Example 21-4 shows the final steps to install the license file on router R1. The example shows the contents of the USB flash drive, with the license file highlighted. It then shows the command to change the licensing on the router.

Example 21-4. Installing a License on the Cisco Router

Click here to view code image

```
R1# dir usbflash1:
Directory of usbflash1:/
1 -rw-4096 Feb 11 2013 17:17:00 FTX1628838P_201302111432454180.lic

7783804928 bytes total (7782912000 bytes free)

R1# license install usbflash1:FTX1628838P_201302111432454180.lic

Installing...Feature:datak9...Successful:Supported
1/1 licenses were successfully installed
0/1 licenses were existing licenses
0/1 licenses were failed to install

R1#
Feb 11 22:35:20.786: %LICENSE-6-INSTALL: Feature datak9 1.0 was installed in this
device. UDI=CISCO2901/K9:FTX1628838P; StoreIndex=1:Primary License Storage
```

```
Feb 11 22:35:21.038: %IOS_LICENSE_IMAGE_APPLICATION-6-LICENSE_LEVEL: Module name =
c2900 Next reboot level = datak9 and License = datak9
```

After a **reload** (not shown), the router now supports the features in the Data feature set. Example 21-5 confirms the change in the licensing status, with the Data license now mirroring the status for the IP Base feature set.

Example 21-5. Verifying the Installed License on a Router

Click here to view code image

```
R1# show license
Index 1 Feature: ipbasek9
Period left: Life time
License Type: Permanent
License State: Active, In Use
License Count: Non-Counted
License Priority: Medium
Index 2 Feature: securityk9
Period left: Not Activated
Period Used: 0 minute 0 second
License Type: EvalRightToUse
License State: Not in Use, EULA not accepted
License Count: Non-Counted
License Priority: None
Index 3 Feature: uck9
Period left: Not Activated
Period Used: 0 minute 0 second
License Type: EvalRightToUse
License State: Not in Use, EULA not accepted
License Count: Non-Counted
License Priority: None
Index 4 Feature: datak9
Period left: Life time
License Type: Permanent
License State: Active, In Use
License Count: Non-Counted
License Priority: Medium
! Lines omitted for brevity
```

You can also verify the installed license using the **show version** command, as shown in Example 21-6.

Example 21-6. Using show version **to Verify Licensing Information**

Click here to view code image

```
R1# show version | begin Technology Package
Technology Package License Information for Module:'c2900'

-----------------------------------------------------------------
Technology Technology-package Technology-package
Current Type Next reboot
------------------------------------------------------------------
ipbase ipbasek9 Permanent ipbasek9
security securityk9 None None
uc None None None
data datak9 Permanent datak9

Configuration register is 0x2102
```

Right-to-Use Licenses

Although a software licensing model may work well in some cases for legitimate Cisco customers, it might not work well in other cases. For instance, when a legitimate Cisco customer wants to test a router feature before they decide to purchase licenses for all their routers, Cisco does not want the mechanics of licensing to get in the way of making that sale. So, Cisco makes the licensing flexible enough to allow use of the licensing without purchasing a PAK.

Cisco has made a few changes over these last few years about how they allow customers to use features without paying for a license. Today, the customer can simply enable most features, without paying for a PAK, for a 60-day evaluation period. After that? The feature stays enabled, with no time limit. The software licensing works on an honor system, asking people to not take advantage.

> **Note**
>
> Cisco may well change their software licensing strategy more over time. Cisco just wants to strike the right balance.

Cisco allows the use of these features today, without a PAK, using a *right-to-use* license. To enable a feature license as a right-to-use license, the engineer needs to use the **license boot module** command, with a reload to allow the router to start using the feature. For instance, Example 21-7 shows how to add the Security feature set to router R1 as a right-to-use evaluation license.

Example 21-7. Activating an Evaluation Right-to-Use License

Click here to view code image

```
R1(config)# license boot module c2900 technology-package securityk9

PLEASE READ THE FOLLOWING TERMS CAREFULLY. INSTALLING THE LICENSE OR
LICENSE KEY PROVIDED FOR ANY CISCO PRODUCT FEATURE OR USING SUCH
PRODUCT FEATURE CONSTITUTES YOUR FULL ACCEPTANCE OF THE FOLLOWING
TERMS. YOU MUST NOT PROCEED FURTHER IF YOU ARE NOT WILLING TO BE BOUND
BY ALL THE TERMS SET FORTH HEREIN.

! The rest of the EULA is omitted...

Activation of the software command line interface will be evidence of
your acceptance of this agreement.


ACCEPT? [yes/no]: yes
% use 'write' command to make license boot config take effect on next boot

Feb 12 01:35:45.060: %IOS_LICENSE_IMAGE_APPLICATION-6-LICENSE_LEVEL: Module name =
c2900 Next reboot level = securityk9 and License = securityk9
Feb 12 01:35:45.524: %LICENSE-6-EULA_ACCEPTED: EULA for feature securityk9 1.0 has
been accepted. UDI=CISCO2901/K9:FTX1628838P; StoreIndex=0:Built-In License Storage
R1(config)# ^Z
```

Once the router is reloaded, the feature set is available, and works just as well as if you had purchased a PAK and downloaded a license file from Cisco.com. Example 21-8 lists the output of the **show license** command again, to show the differences in how the command lists the results of the installation of a right-to-use license.

Example 21-8. Activating an Evaluation Right-to-Use License

Click here to view code image

```
R1# show license
Index 1 Feature: ipbasek9
Period left: Life time
License Type: Permanent
License State: Active, In Use
License Count: Non-Counted
License Priority: Medium
Index 2 Feature: securityk9
Period left: 8 weeks 4 days
Period Used: 0 minute 0 second
License Type: EvalRightToUse
License State: Active, In Use
License Count: Non-Counted
License Priority: Low
Index 3 Feature: uck9
Period left: Not Activated
Period Used: 0 minute 0 second
License Type: EvalRightToUse
```

```
    License State: Not in Use, EULA not accepted
    License Count: Non-Counted
    License Priority: None
    Index 4 Feature: datak9
    Period left: Life time
    License Type: Permanent
    License State: Active, In Use
    License Count: Non-Counted
    License Priority: Medium
    ! Lines omitted for brevity
```

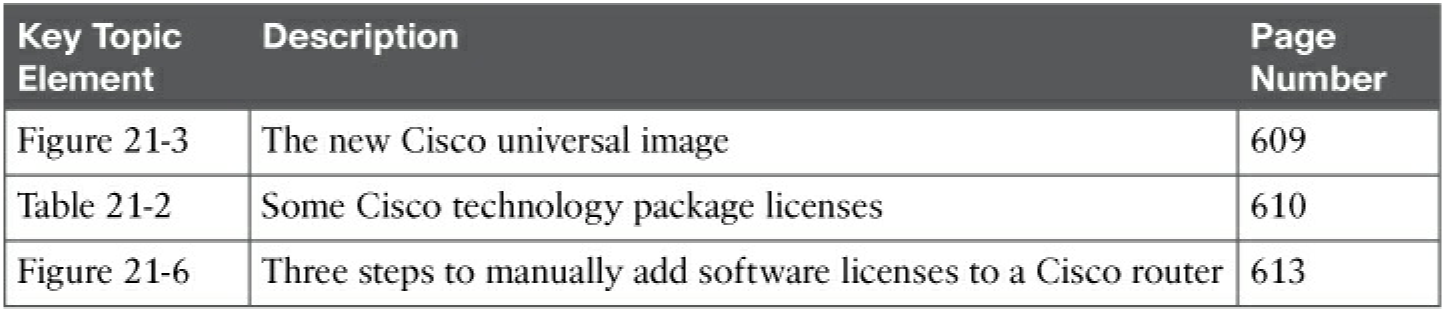
In this example, the IP Base and Data licenses are permanent, but the right-to-use license appears to have only 60 days left (8 weeks, 4 days). The first 60 days is considered an evaluation period. The output continues over time to count downward toward 0 days left, at which point, with the current rules as the time of publication of this book, it converts to a lifetime time period.

Exam Preparation Tasks

Review All the Key Topics

Review the most important topics from this chapter, noted with the Key Topic icon. Table 21-3 lists these key topics and where each is discussed.

Table 21-3. Key Topics for Chapter 21



Key Topic Element	Description	Page Number
Figure 21-3	The new Cisco universal image	609
Table 21-2	Some Cisco technology package licenses	610
Figure 21-6	Three steps to manually add software licenses to a Cisco router	613

Complete the Tables and Lists from Memory

Print a copy of DVD Appendix D, "Memory Tables," or at least the section for this chapter, and complete the tables and lists from memory. DVD Appendix E, "Memory Tables Answer Key," includes completed tables and lists to check your work.

Definitions of Key Terms

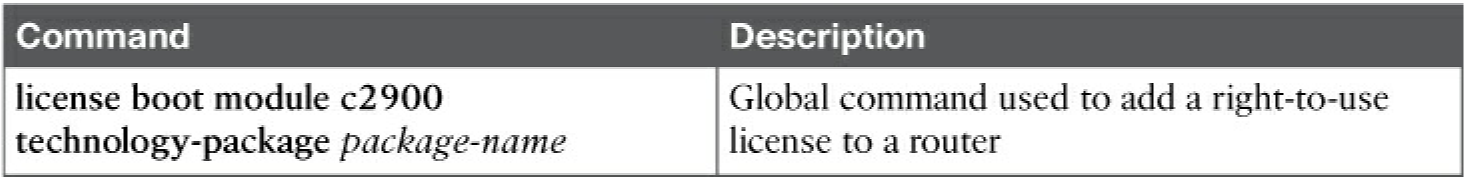
After your first reading of the chapter, try to define these key terms, but do not be concerned about getting them all correct at that time. Chapter 22 directs you in how to use these terms for late-stage preparation for the exam.

IOS feature set
universal image
product activation key (PAK)
universal device identifier (UDI)

Command Reference to Check Your Memory

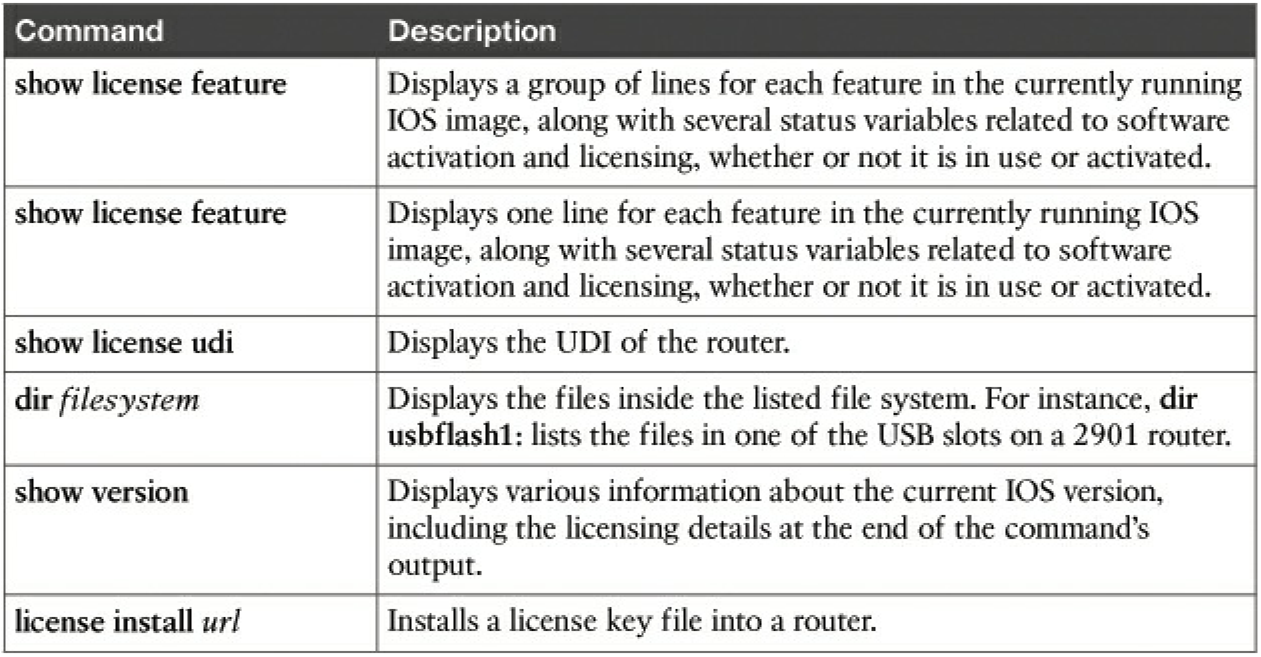
Although you should not necessarily memorize the information in the tables in this section, this section does include a reference for the configuration and EXEC commands covered in this chapter. Practically speaking, you should memorize the commands as a side effect of reading the chapter and doing all the activities in this exam preparation section. To check to see how well you have memorized the commands as a side effect of your other studies, cover the left side of the table with a piece of paper, read the descriptions on the right side, and see whether you remember the command.

Table 21-4. Chapter 21 Configuration Command Reference



Command	Description
license boot module c2900 technology-package *package-name*	Global command used to add a right-to-use license to a router

Table 21-5. Chapter 21 EXEC Command Reference

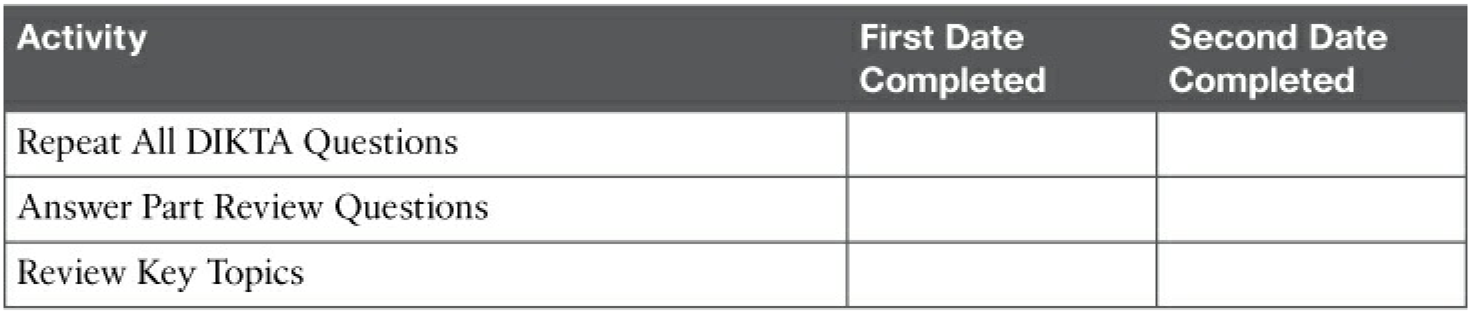


Command	Description
show license feature	Displays a group of lines for each feature in the currently running IOS image, along with several status variables related to software activation and licensing, whether or not it is in use or activated.
show license feature	Displays one line for each feature in the currently running IOS image, along with several status variables related to software activation and licensing, whether or not it is in use or activated.
show license udi	Displays the UDI of the router.
dir *filesystem*	Displays the files inside the listed file system. For instance, **dir usbflash1:** lists the files in one of the USB slots on a 2901 router.
show version	Displays various information about the current IOS version, including the licensing details at the end of the command's output.
license install *url*	Installs a license key file into a router.

Part VI Review

Keep track of your part review progress with the checklist in Table P6-1. Details about each task follow the table.

Table P6-1. Part VI Part Review Checklist



Activity	First Date Completed	Second Date Completed
Repeat All DIKTA Questions		
Answer Part Review Questions		
Review Key Topics		

Repeat All DIKTA Questions

For this task, answer the "Do I Know This Already?" questions again for the chapters in Part I of this book using the PCPT software. See the section "How to View Only DIKTA Questions by Part" in the Introduction to this book to learn how to make the PCPT software show you DIKTA questions for this part only.

Answer Part Review Questions

For this task, answer the Part Review questions for this part of the book using the PCPT software. See the section "How to View Only DIKTA Questions by Part" in the Introduction to this book to learn how to make the PCPT software show you DIKTA questions for this part only.

Review Key Topics

Key Topic

Browse back through the chapters, and look for the Key Topic icons. If you do not remember some details, take the time to reread those topics.

Part VII: Final Review

Chapter 22: Final Review

Chapter 22. Final Review

Congratulations! You made it through the book, and now it's time to finish getting ready for the exam. This chapter helps you get ready to take and pass the exam in three ways.

This chapter begins by talking about the exam itself. You know the content and topics. Now you need to think about what happens during the exam and what you need to do in these last few weeks before taking the exam. At this point, everything you do should focus on getting you ready to pass so that you can finish up this hefty task.

The second section of this chapter gives you some exam review tasks as your final preparation for your ICND1, ICND2, or CCNA exam.

Advice About the Exam Event

Now that you have finished the bulk of this book, you could just register for your Cisco ICND1, ICND2, or CCNA exam, show up, and take the exam. However, if you spend a little time thinking about the exam event itself, learning more about the user interface of the real Cisco exams, and the environment at the Vue testing centers, you will be better prepared, particularly if this is your first Cisco exam. This first of three major sections in this chapter gives some advice about the Cisco exams and the exam event itself.

Learn the Question Types Using the Cisco Certification Exam Tutorial

In the weeks leading up to your exam, think more about the different types of exam questions and have a plan for how to approach those questions. One of the best ways to learn about the exam questions is to use the Cisco Exam Tutorial.

To find the Cisco Certification Exam Tutorial, go to www.cisco.com and search for "exam tutorial." The tutorial sits inside a web page with a flash presentation of the exam user interface. The tutorial even lets you take control as if you were taking the exam. When using the tutorial, make sure you take control and try the following:

- Try to click **Next** on the multiple choice single-answer question without clicking an answer and see that the testing software tells you that you have too few answers.
- On the multiple choice multi-answer questions, select too few answers and click **Next**, to again see how the user interface responds.
- In the drag-and-drop question, drag the answers to the obvious answer locations, but them drag them back to the original location. (You might do this on the real exam if you change your mind when answering the question.)
- On the simulation questions, first just make sure you can get to the command-line interface (CLI) on one of the routers. To do so, you have to click the PC icon for a PC connected to the router console; the console cable appears as a dashed line, and network cables are solid lines.
- Still on the sim questions, look at the scroll areas at the top, side, and in the terminal emulator window.
- Still on the sim question, make sure that you can toggle between the topology window and the terminal emulator window by clicking **Show Topology** and **Hide Topology**.
- On the testlet questions, answer one multiple choice question, move to the second and answer it, and then move back to the first question, confirming that inside a testlet, you can move around between questions.
- Again on the testlet questions, click the **Next** button to see the pop-up window that Cisco uses as a prompt to ask if you want to move on. Testlets may actually allow you to give too few answers and still move on. Once you click to move past the testlet, you cannot go back to change your answer for any of these questions.

Think About Your Time Budget Versus Numbers of Questions

On exam day, you need to keep an eye on your speed. Going too slowly hurts you because you might not have time to answer all the questions. Going too fast might be hurtful if your fast speed is because you are rushing and not taking the time to fully understand the questions. So, you need to be able to somehow know if you are moving quickly enough to answer all the questions while not rushing.

The exam user interface shows some useful information, namely a countdown timer and a question counter. The question counter shows a question number for the question you are answering, and it shows the total number of questions on your exam.

Unfortunately, treating each question as equal does not give you an accurate time estimate. For instance, if your exam allows 90 minutes, and your exam has 45 questions, you have 2 minutes per question. After answering 20 questions, if you have taken 40 minutes, you are right on time. However, several factors make that kind of estimate difficult.

First, Cisco does not tell us beforehand the exact number of questions for each exam. For instance, the Cisco website might list the CCNA exam as having from 45 to 55 questions. (The ICND1 and ICND2 exams have similar ranges.) But you do not know how many questions are on your exam until it begins, when you go through the screens that lead up to the point where you click Start Exam.

Next, some questions (call them *time burners*) clearly take a lot more time to answer:

Normal time questions: Multiple choice and drag-and-drop, approximately 1 minute

Time burners: Sims, simlets, and testlets, approximately 6 to 8 minutes

Finally, in the count of 45 to 55 questions on a single exam, even though testlet and simlet questions contain several multiple choice questions, the exam software counts each testlet and simlet question as one question in the question counter. For instance, if a testlet question has four embedded multiple choice questions, in the exam software's question counter that counts as one question.

Note

Cisco does not tell us why you might get 45 questions while someone else taking the same exam might get 55 questions, but it seems reasonable to think that the person with 45 questions might have a few more of the time burners, making the two exams equivalent.

You need a plan for how you will check your time, a plan that does not distract you from the exam. It might worth taking a bit of a guess, to keep things simple, like this:

> If you have 50 questions and 90 minutes, you have a little less than 2 minutes per question. Just guess a little based on how many time burner questions you have seen so far.

No matter how you plan to check your time, think about it before exam day. You can even use the method listed under the next heading.

A Suggested Time-Check Method

You can use the following math to do your time check in a way that weights the time based on those time burner questions. You do not have to use this method at all. But, to keep it simple, this math uses only addition of whole numbers. It gives you a pretty close time estimate, in my opinion.

The concept is simple. Just do a simple calculation that estimates the time you should have used so far. Here's the math:

> (Number of questions answered so far) + (7 per time burner)

Then, you check the timer to figure out how much time you have spent:

- You have used exactly that much time, or a little more: your timing is perfect.
- You have used less time: you are ahead of schedule.
- You have used noticeably more time: you are behind schedule.

For instance, if you have already finished 17 questions, 2 of which were time burners, your time estimate is 17 + 7 + 7 = 31 minutes. If your actual time is also 31 minutes, or maybe 32 or 33 minutes, you are right on schedule. If you have spent less than 31 minutes, you are ahead of schedule.

So, the math is pretty easy: Questions answered plus 7 per time burner is the guesstimate of how long you should take if you are right on time.

Note

This math is an estimate; we make no guarantees that the math will be an accurate predictor on every exam.

Miscellaneous Pre-Exam Suggestions

Here are just a few more suggestions for things to think about before exam day arrives:

- Get some earplugs. Testing centers often have some, but if you do not want to chance it, come prepared. The testing center is usually a room inside the space of a company that does something else as well (often a training center). So, there are people talking in nearby rooms and other office noises. Earplugs can help. (Headphones, as electronic devices, would not be allowed.)
- Some people like to spend the first minute of the exam writing down some notes for reference. For instance, maybe you want to write down the table of magic numbers for finding IPv4 subnet IDs. If you plan to do that, practice making those notes. Before each practice exam, transcribe those lists, just like you expect to do at the real exam.
- Plan your travel to the testing center with enough time so that you will not be rushing to make it just in time.
- If you tend to be nervous before exams, practice your favorite relaxation techniques for a few minutes before each practice exam, just to be ready to use them.

Exam-Day Advice

I hope the exam goes well for you. Certainly, the better prepared you are, the better chances you have on the exam. But these small tips can help you do your best on exam day:

- Rest the night before the exam rather than stay up late to study. Clarity of thought is more important than one extra fact, especially because the exam requires so much analysis and thinking rather than just remembering facts.
- If you did not bring earplugs, ask the testing center for some, even if you cannot imagine using them. You never know whether it might help.
- You may bring personal effects into the building and testing company's space but not into the actual room in which you take the exam. So, take as little extra stuff with you as possible. If you have a safe place to leave briefcases, purses, electronics, and so on, leave them there. However, the testing center should have a place to store your things as well. Simply put, the less you bring, the less to worry about storing. (For example, I have even been asked to remove my analog wristwatch on more than one occasion.)
- The exam center gives you a laminated sheet (and pen), as a place to take notes. (They usually do not let you bring paper and pen into the room, even if supplied by the testing center.)
- Leave for the testing center with extra time so that you do not have to rush.
- Try to find a restroom before going into the testing center. If you cannot find one, you can use the one in the testing

center, of course, and they will direct you and give you time before your exam starts.

- Do not drink a 64-ounce drink on the way to the testing center; once the exam starts, the exam timer will not stop while you go to the restroom.
- On exam day, use any relaxation techniques that you have practiced to help get your mind focused while you wait for the exam.

Exam Review

This Exam Review completes the study plan materials as suggested by this book. At this point, you have read the other chapters of the book, and you have done the Chapter Review exam preparation tasks and Part Review tasks. Now you need to do the final study and review activities before taking the exam, as detailed in this section.

This section suggests some new activities and reminds you of some you probably already know. Whether you find these new or old, though, the activities all focus on filling in your knowledge gaps, finishing off your skills, and completing the study process. While repeating some tasks you did at Chapter Review and Part Review can help, you need to be ready to take an exam, so the Exam Review asks you to spend a lot of time answering exam questions.

The Exam Review walks through suggestions for several types of tasks and gives you some tracking tables for each activity. The main categories are as follows:

- Practicing for speed
- Taking practice exams
- Finding what you do not know well yet (knowledge gaps)
- Configuring and verifying functions from the CLI
- Repeating the Chapter Review and Part Review tasks

Practice Subnetting and Other Math-Related Skills

Like it or not, some of the questions on the Cisco ICND1, ICND2, and CCNA exams require you to do some math. To pass, you have to be good at the math. You also need to know when to use each process.

Interestingly, both the ICND1 and ICND2 exams require this math, but Cisco put the core learning for these math skills in the ICND1 exam topics. As a result, all these math skills are considered prerequisites for the ICND2 exam, but you still have to be good at the math. In particular, ICND2 has many troubleshooting topics, and all these require that you be pretty comfortable with all the subnetting math.

No matter how you learned subnetting before picking up this book, you should review the concepts and math before taking the ICND2 or CCNA exam. Table 22-1 lists the topics that require speed, and Table 22-2 lists items for which the speed is probably less important. By this point in your study, you should already be confident at finding the right answer to these kinds of problems. Now is the time to finish off your skills at getting the right answers, plus getting faster so you reduce your time pressure on the exams.

Table 22-1. Math-Related Activities That Benefit from Speed Practice

Activity	Book's Excellent Speed Goal (Seconds)	Self Check: Date / Time	Self Check: Date / Time
From a unicast IPv4 address, find key facts about its classful network.	10		
From one mask in any format, convert to the other two mask formats.	10		
Given an IPv4 address and mask, find the number of network, subnet, and host bits, plus the number of hosts/subnet and number of subnets.	15		
Given an IPv4 address and mask, find the resident subnet, subnet broadcast address, and range of usable addresses.	20-30		
Given a set of mask requirements, choose the best subnet mask.	15		
Given a classful network and one mask, find all subnet IDs.	45		

Table 22-2. Math-Related Activities That May Be Less Time Sensitive

ICND1 Book Chapter	Activity	Self Check: Date / Time	Self Check: Date / Time
20	Find VLSM overlaps, with problems that contain 5 or 6 subnets.		
20	Add VLSM subnets, with problems that contain 5 or 6 subnets.		
21	Find the best summary route, with problems that list 4 routes.		
22	Build an ACL command to match a subnet's addresses.		
22	List the addresses matched by one existing ACL command.		
25	Find the best abbreviation for one IPv6 address.		
27	Find the IPv6 address of one router interface when using EUI-64.		

Note

The time goals in the table are goals chosen by the author to give you an idea of a good time. If you happen to be a little slower on a few tasks, that does not mean you cannot do well on the test. But if you take several times as much time, for almost every task, know that the math-related work may cause you some time problems.

Take Practice Exams

One day soon, you need to pass a real Cisco exam at a Vue testing center. So, it is time to practice the real event as much as possible.

A practice exam using the Pearson IT Certification Practice Test (PCPT) exam software lets you experience many of the same issues as when taking a real Cisco exam. The software gives you a number of questions, with a countdown timer shown in the window. Once you answer a question, you cannot go back to it (yes, that's true on Cisco exams). If you run out of time, the questions you did not answer count as incorrect.

The process of taking the timed practice exams helps you prepare in three key ways:

- To practice the exam event itself, including time pressure, the need to read carefully, with a need to concentrate for long periods
- To build your analysis and critical thinking skills when examining the network scenario built in to many questions
- To discover the gaps in your networking knowledge so that you can study those topics before the real exam

As much as possible, treat the practice exam events as if you were taking the real Cisco exam at a Vue testing center. The following list gives some advice on how to make your practice exam more meaningful, rather than as just one more thing to do before exam day rolls around:

- Set aside 2 hours for taking the 90-minute timed practice exam.
- Make a list of what you expect to do for the 10 minutes before the real exam event. Then visualize yourself doing those things. Before taking each practice exam, practice those final 10 minutes before your exam timer starts. (The earlier section titled "Exam Day Advice" lists some suggestions about what to do in those last 10 minutes.)
- You may not bring anything with you into the Vue exam room, so remove all notes and helps from your work area before taking a practice exam. You may use blank paper, pen, and your brain only. Do not use calculators, notes, web browsers, or any other app on your computer.
- Real life may get in the way, but if at all possible, ask anyone around you to leave you alone for the time you will practice. If you must do your practice exam in a distracting environment, wear headphones or earplugs to reduce distractions.
- Do not guess, hoping to improve your score. Answer only when you have confidence in the answer. Then, if you get the question wrong, you can go back and think more about the question in a later study session.

Practicing Taking the ICND2 Exam

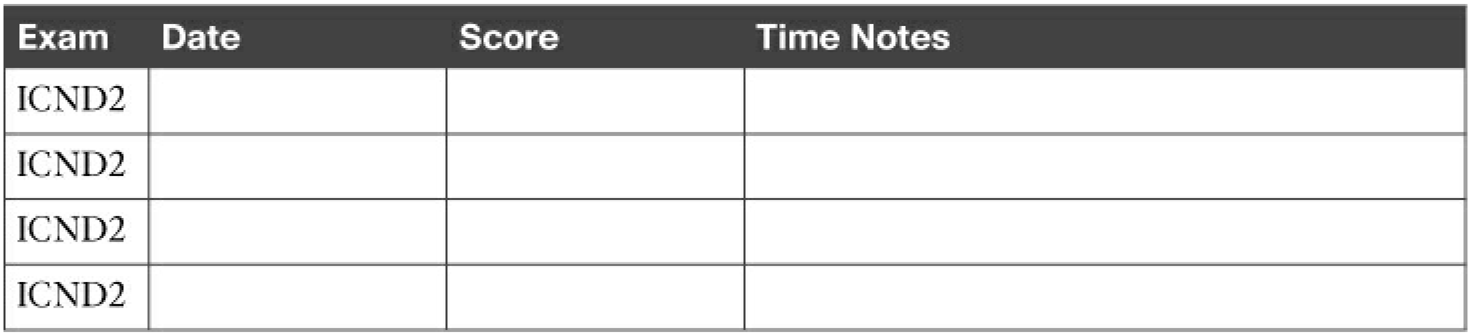
Because you are reading this chapter in the *Cisco CCNA Routing and Switching ICND2 200-101 Official Cert Guide*, you should be preparing for either the ICND2 exam or the CCNA exam. The PCPT exam software, and the exams you get with this ICND2 book, let you take practice exams for both the ICND2 and CCNA exams.

To take an ICND2 practice exam, you need to select one or both of the ICND2 exams from PCPT. If you followed the study plan in this book, you will not have seen any of the questions in these two exam databases before now. Once you select one of these two exams, you just need to choose the **Practice Exam** option in the upper right and start the exam.

You should plan to take between one and three ICND2 practice exams with these exam databases. Even people who are already well prepared should do at least one practice exam, just to experience the time pressure and the need for prolonged concentration. For those who want more practice exams, these two exam databases have enough questions for more than two exams. As a result, if you took a fourth practice exam with these exam databases, you will have seen almost all the questions before, making the practice exam a little too easy. If you are interested in purchasing more practice exams, check out the *Cisco CCNA Routing and Switching ICND2 200-101 Official Cert Guide Premium Edition eBook and Practice Test* product at www.ciscopress.com/title/9780133367713 and be sure to use the 70 percent discount coupon included in the DVD sleeve of this book.

Table 22-3 gives you a checklist to record your different practice exam events. Note that recording both the date and the score is helpful for some other work you will do, so note both. Also, in the Time Notes section, if you finish on time, note how much extra time you had; if you run out of time, note how many questions you did not have time to answer.

Table 22-3. ICND2 Practice Exam Checklist



Exam	Date	Score	Time Notes
ICND2			
ICND2			
ICND2			
ICND2			

Practicing Taking the CCNA Exam

If you plan on using the one-exam path to CCNA Routing and Switching, and taking the CCNA exam, you should plan on taking CCNA practice exams, and avoid the ICND1 and ICND2 practice exams. The CCNA practice exams use the same mix of questions as do the ICND1 and ICND2 practice exams, and it is best to save those questions for your CCNA practice exams.

Both the ICND1 book and the ICND2 book give you the rights to two CCNA exam question banks. If you own only one of those two books, simply use the two exams with "CCNA Full Exam" in the title. If you own both books, you have two sets of two

CCNA exam banks, for a total of four unique CCNA exams. Figure 22-1 shows the ideas and the names of the exam in the PCPT software.

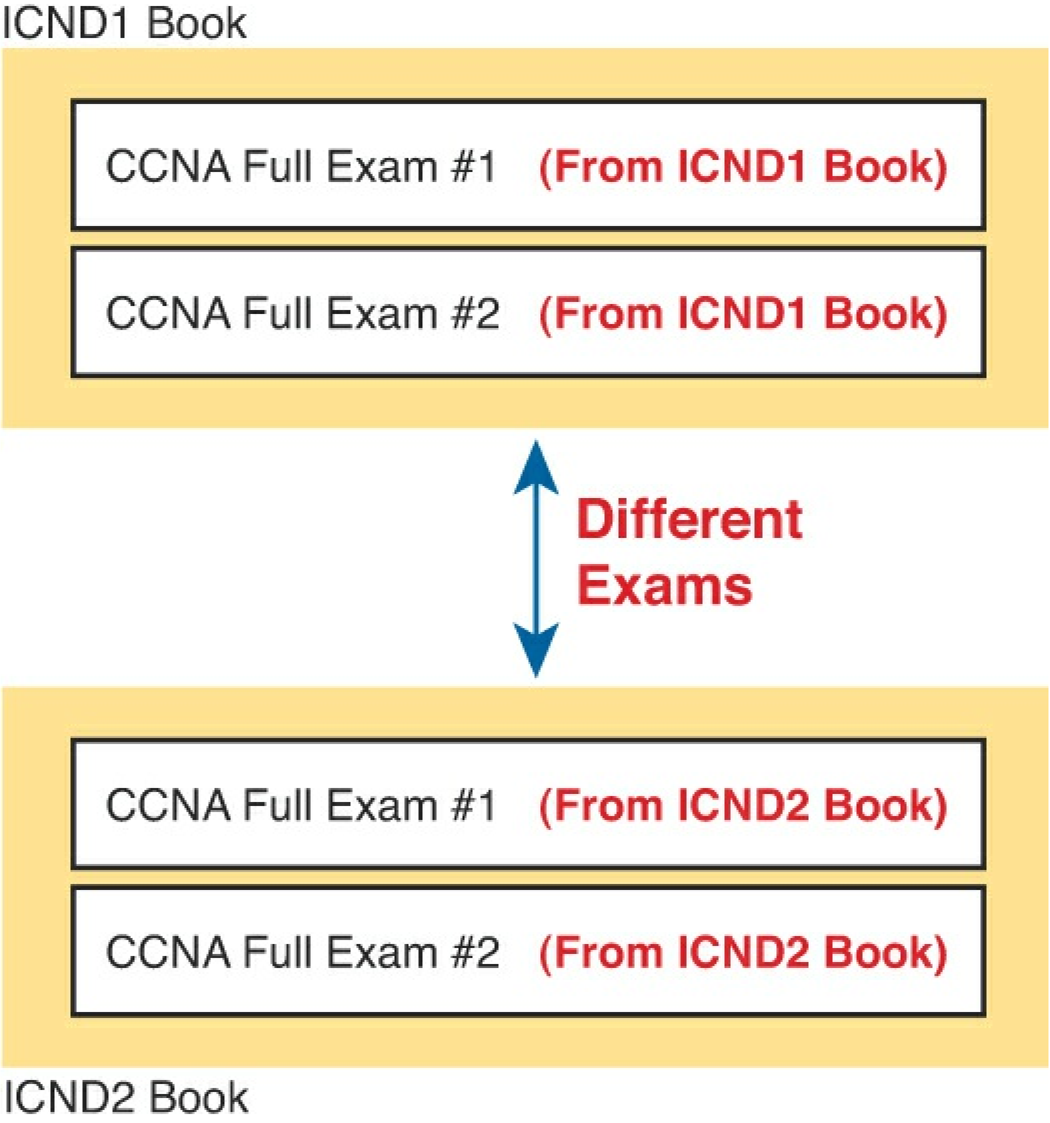

ICND1 Book
CCNA Full Exam #1 (From ICND1 Book)
CCNA Full Exam #2 (From ICND1 Book)
Different Exams
CCNA Full Exam #1 (From ICND2 Book)
CCNA Full Exam #2 (From ICND2 Book)
ICND2 Book

Figure 22-1. CCNA Exam Banks in the ICND1 and ICND2 Books

To take a CCNA exam, select one of the CCNA exam databases from the PCPT window. Then choose the mode option of **Practice Exam**, and start the exam.

For CCNA practice exam, plan to take at least one practice exam, but you could take up to four practice exams using these exam databases. Table 22-4 gives you a checklist to record your different practice exam events. Note that recording both the date and the score is helpful for some other work you will do, so note both. Also, in the Time Notes section, if you finish on time, note how much extra time you had; if you run out of time, note how many questions you did not have time to answer.

Table 22-4. CCNA Practice Exam Checklist

Exam Database Name	Date	Score	Time Notes
CCNA Exam 1 (From ICND1 Book)			
CCNA Exam 2 (From ICND1 Book)			
CCNA Exam 1 (From ICND2 Book)			
CCNA Exam 2 (From ICND2 Book)			

Note

The PCPT software lists, for the ICND2 book, two exam databases with the name ICND2 and two with the name CCNA. The questions in these two pair of exam databases overlap, so it makes sense to either take ICND2 practice exams or CCNA practice exams, depending on what test you are preparing for, but not both.

Advice on How to Answer Exam Questions

Open a web browser. Yes, take a break, and open a web browser, on any device. Do a quick search on a fun topic. Then, before you click a link, get ready to think where your eyes go for the first 5 to 10 seconds after you click the link. Now, click a link, and look at the page. Where did your eyes go?

Interestingly, web browsers, and the content in those web pages, have trained us all to scan. Web page designers actually design content with the expectation that people will scan with different patterns. Regardless of the pattern, when reading a web page, almost no one reads sequentially, and no one reads entire sentences. They scan for the interesting graphics, the big words, and then scan the space around those noticeable items.

Other parts of our electronic culture have also changed how the average person reads. For instance, many of you grew up using texting and social media, sifting through hundreds or thousands of messages, but each messages barely fills an entire sentence. (In fact, that previous sentence would not fit in a tweet, being longer than 140 characters.)

Those every day habits have changed how we all read and think in front of a screen. Unfortunately, those same habits often hurt our scores when taking computer-based exams.

If you scan exam questions like you read web pages, texts, and tweets, you will probably make some mistakes because you missed a key fact in the question, answer, or exhibits. It helps to start at the beginning, and read all the words—a process that is amazingly unnatural for many people today.

> **Note**
>
> I have heard from many college professors, in multiple disciplines, and Cisco Networking Academy instructors, and they consistently tell me that the number one test taking issue today is that people do not read the question well enough to understand the details.

For when you are taking the practice exams, and answering individual questions, let me make two suggestions. First, before the practice exam, think about your own personal strategy for how you will read a question. Make your approach to multiple choice questions in particular be a conscious decision on your part. Second, if you want some suggestions on how to read an exam question, use the following strategy:

Step 1. Read the question itself, thoroughly, from start to finish.

Step 2. Scan any exhibit (usually command output) or figure.

Step 3. Scan the answers to look for the types of information. (Numeric? Terms? Single words? Phrases?)

Step 4. Reread the question, thoroughly, from start to finish, to make sure you understand it.

Step 5. Read each answer thoroughly, while referring to the figure/exhibit as needed. After reading each answer, before reading the next answer, do the following:

- **A.** If correct, select as correct.
- **B.** If for sure incorrect, mentally rule it out.
- **C.** If unsure, mentally note it as a possible correct answer.

> **Note**
>
> Cisco exams will tell you the number of correct answers. The exam software also helps you finish the question with the right number of answers noted. For instance, the software prevents you from selecting too many answers. Also, if you try to move on to the next question but have too few answers noted, the exam software asks if you truly want to move on.

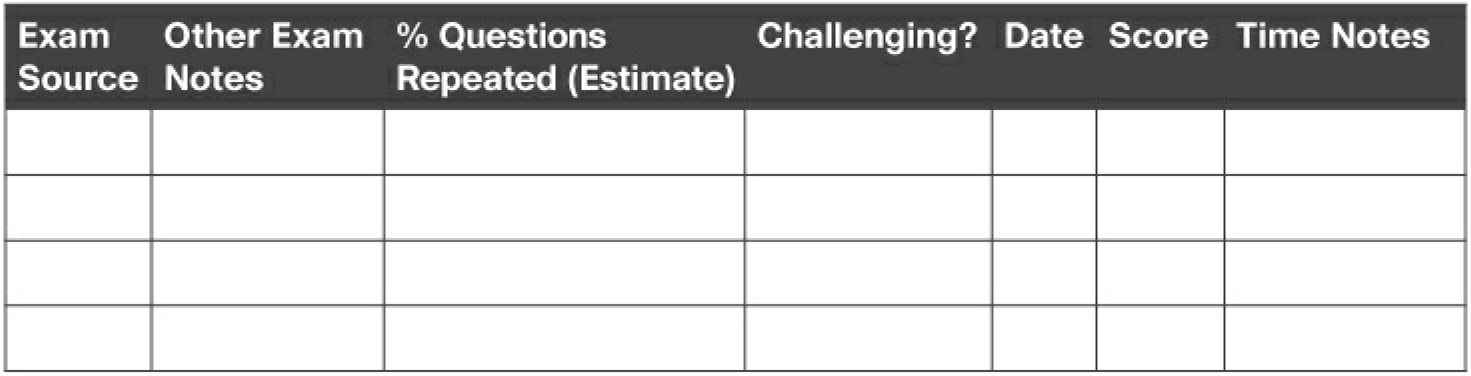
Use the practice exams as a place to practice your approach to reading. Every time you click to the next question, try to read the question following your approach. If you are feeling time pressure, that is the perfect time to keep practicing your approach, to reduce and eliminate questions you miss because of scanning the question instead of reading thoroughly.

Taking Other Practice Exams

Many people add other practice exams and questions other than the questions that come with this book. Frankly, using other practice exams in addition to the questions that come with this book can be a good idea, for many reasons. The other exam questions may use different terms in different ways, emphasize different topics, and show different scenarios that make you rethink some topics.

No matter where you get additional exam questions, if you use the exam questions for a timed practice exam, it helps to take a few notes about the results. Table 22-5 gives you a place to take those notes. Also, take a guess at the percent of questions you have seen before taking the exam, and note if you think the questions are less, more, or the same challenge level as the questions that come with this book. And as usual, note whether you ran out of time or had extra time left over at the end.

Table 22-5. Checklist for Practice Exams from Other Sources



Exam Source	Other Exam Notes	% Questions Repeated (Estimate)	Challenging?	Date	Score	Time Notes

Note that the publisher does sell products that include additional test questions. The *Cisco CCNA Routing and Switching ICND2 Premium Edition eBook and Practice Test* product is basically the publisher's eBook version of this book. It includes a softcopy of the book, in formats you can read on your computer or on the most common book readers and tablets. The product includes all the content you would normally get with the DVD that comes with the print book, including all the question databases mentioned in this chapter. In addition, this product includes two more ICND2 exam database, plus two more CCNA exam databases, for extra exams.

> **Note**
>
> In addition to getting the extra questions, the Premium Editions have links to every test question, including those in the print book, to the specific section of the book for further reference. This is a great learning tool if you need more detail than what you find in the question explanations. You can purchase the eBooks and additional practice exams at 70 percent off the list price using the coupon on the back of the activation code card in the DVD sleeve, making the Premium Editions the best and most cost-efficient way to get more practice questions.

Find Knowledge Gaps Through Question Review

You just took a number of practice exams. You probably learned a lot, gained some exam taking skills, and improved your networking knowledge and skills. But if you go back and look at all the questions you missed, you might be able to find a few small gaps in your knowledge.

One of the hardest things to find when doing your final exam preparation is to discover gaps in your knowledge and skills. In other words, what topics and skills do you need to know that you do not know? Or what topics do you think you know, but you misunderstand about some important fact? Finding gaps in your knowledge at this late stage requires more than just your gut feel about your strengths and weaknesses.

This next task uses a feature of PCPT to help you find those gaps. The PCPT software tracks each practice exam you take, remembering your answer for every question, and whether you got it wrong. You can view the results, and move back and forth between seeing the question and seeing the results page. To find gaps in your knowledge, follow these steps:

Step 1. Pick and review one of your practice exams.

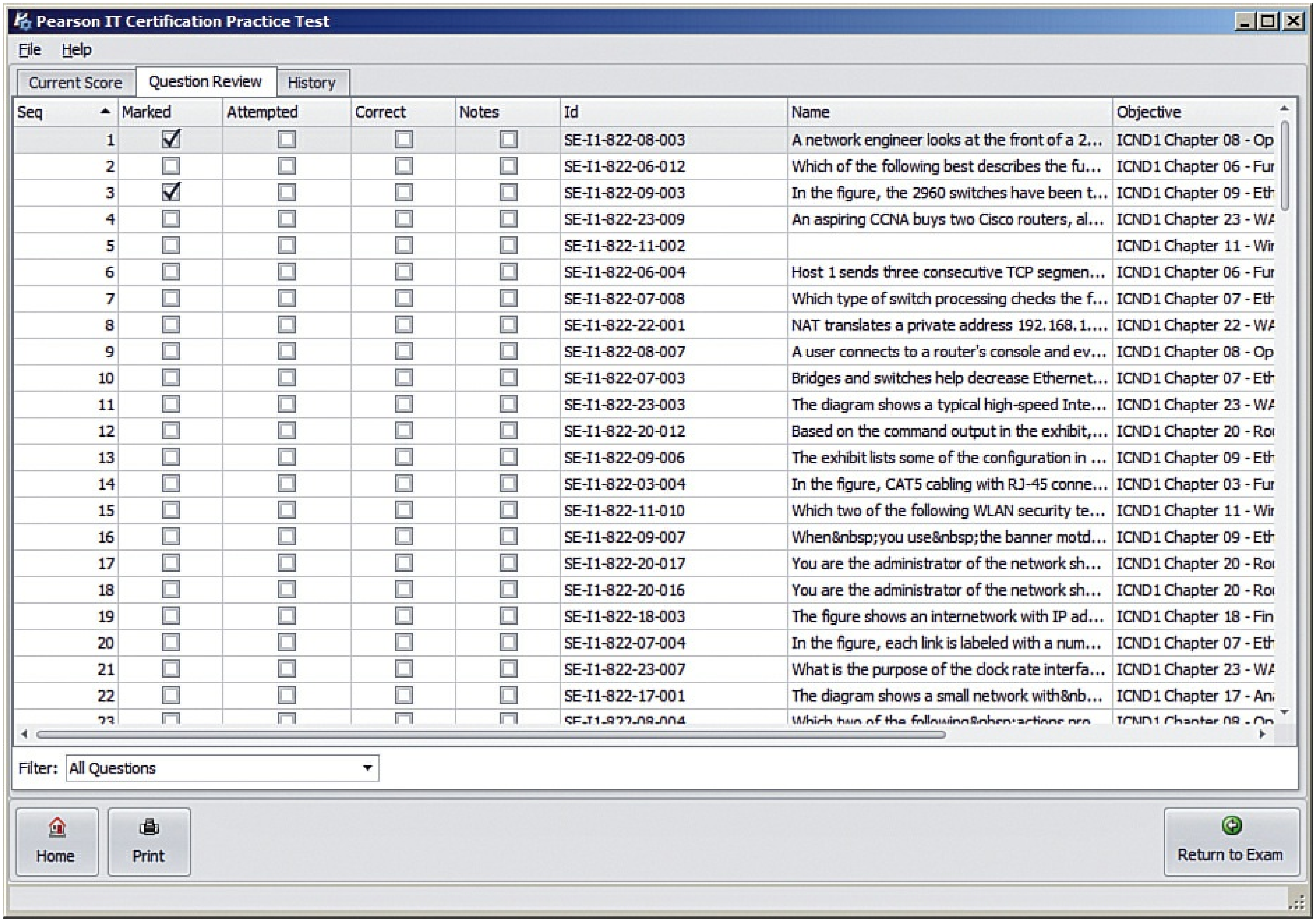
Step 2. Review each incorrect question until you are happy you understand the question.

Step 3. When finished with your review for a question, mark the question.

Step 4. Review all incorrect questions from your exam until all are marked.

Step 5. Move on to the next practice exam.

Figure 22-2 shows a sample Question Review page, in which all the questions were answered incorrectly. The results list a Correct column, with no check mark meaning that the answer was incorrect.

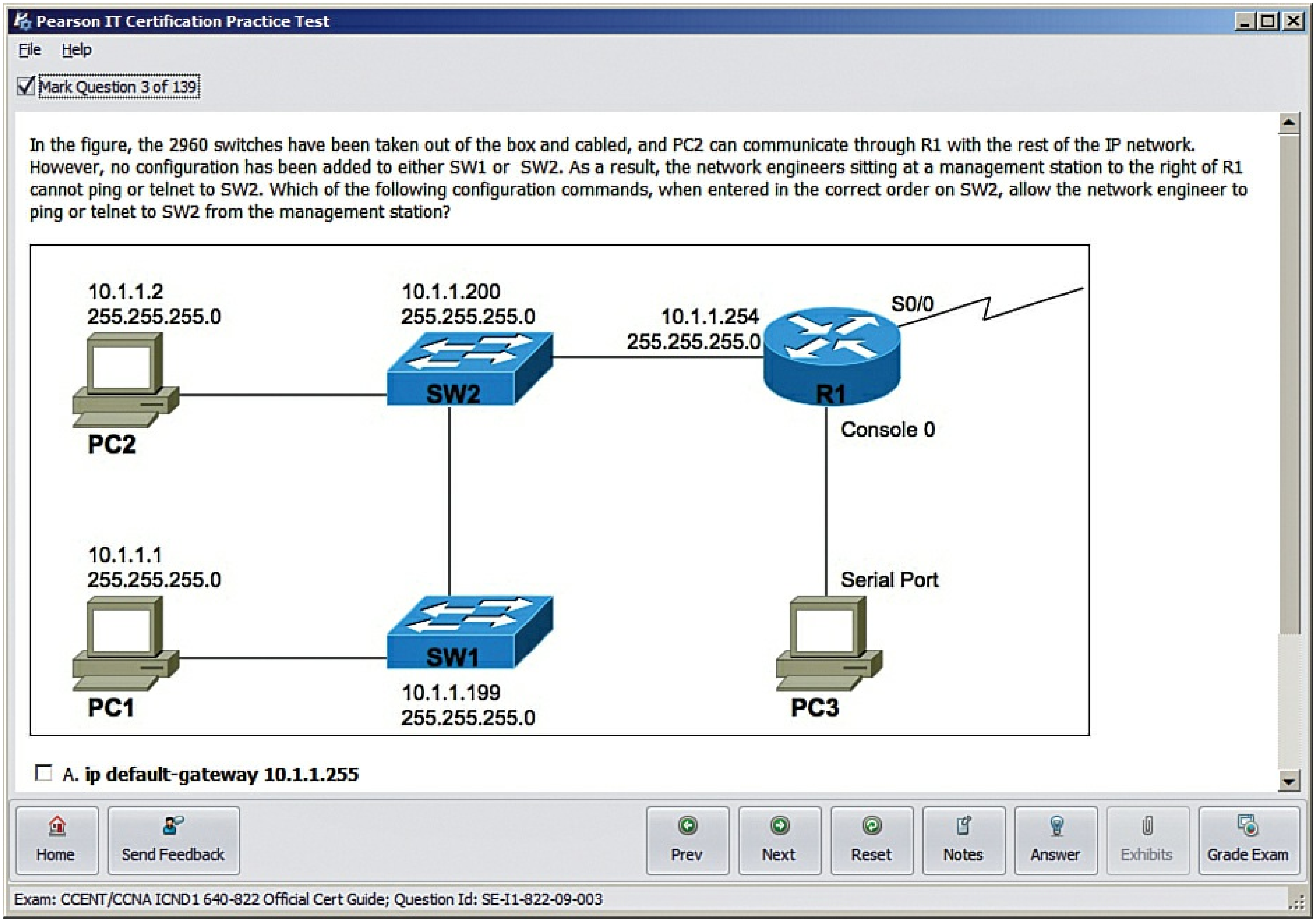


Seq	Marked	Attempted	Correct	Notes	Id	Name	Objective
1	☑	☐	☐	☐	SE-I1-822-08-003	A network engineer looks at the front of a 2...	ICND1 Chapter 08 - Op
2	☐	☐	☐	☐	SE-I1-822-06-012	Which of the following best describes the fu...	ICND1 Chapter 06 - Fur
3	☑	☐	☐	☐	SE-I1-822-09-003	In the figure, the 2960 switches have been t...	ICND1 Chapter 09 - Eth
4	☐	☐	☐	☐	SE-I1-822-23-009	An aspiring CCNA buys two Cisco routers, al...	ICND1 Chapter 23 - WA
5	☐	☐	☐	☐	SE-I1-822-11-002		ICND1 Chapter 11 - Wir
6	☐	☐	☐	☐	SE-I1-822-06-004	Host 1 sends three consecutive TCP segmen...	ICND1 Chapter 06 - Fur
7	☐	☐	☐	☐	SE-I1-822-07-008	Which type of switch processing checks the f...	ICND1 Chapter 07 - Eth
8	☐	☐	☐	☐	SE-I1-822-22-001	NAT translates a private address 192.168.1....	ICND1 Chapter 22 - WA
9	☐	☐	☐	☐	SE-I1-822-08-007	A user connects to a router's console and ev...	ICND1 Chapter 08 - Op
10	☐	☐	☐	☐	SE-I1-822-07-003	Bridges and switches help decrease Ethernet...	ICND1 Chapter 07 - Eth
11	☐	☐	☐	☐	SE-I1-822-23-003	The diagram shows a typical high-speed Inte...	ICND1 Chapter 23 - WA
12	☐	☐	☐	☐	SE-I1-822-20-012	Based on the command output in the exhibit,...	ICND1 Chapter 20 - Rou
13	☐	☐	☐	☐	SE-I1-822-09-006	The exhibit lists some of the configuration in ...	ICND1 Chapter 09 - Eth
14	☐	☐	☐	☐	SE-I1-822-03-004	In the figure, CAT5 cabling with RJ-45 conne...	ICND1 Chapter 03 - Fur
15	☐	☐	☐	☐	SE-I1-822-11-010	Which two of the following WLAN security te...	ICND1 Chapter 11 - Wir
16	☐	☐	☐	☐	SE-I1-822-09-007	When you use the banner motd...	ICND1 Chapter 09 - Eth
17	☐	☐	☐	☐	SE-I1-822-20-017	You are the administrator of the network sh...	ICND1 Chapter 20 - Rou
18	☐	☐	☐	☐	SE-I1-822-20-016	You are the administrator of the network sh...	ICND1 Chapter 20 - Rou
19	☐	☐	☐	☐	SE-I1-822-18-003	The figure shows an internetwork with IP ad...	ICND1 Chapter 18 - Fin
20	☐	☐	☐	☐	SE-I1-822-07-004	In the figure, each link is labeled with a num...	ICND1 Chapter 07 - Eth
21	☐	☐	☐	☐	SE-I1-822-23-007	What is the purpose of the clock rate interfa...	ICND1 Chapter 23 - WA
22	☐	☐	☐	☐	SE-I1-822-17-001	The diagram shows a small network with&nb...	ICND1 Chapter 17 - Ana
23	☐	☐	☐	☐	SE-I1-822-08-004	Which two of the following actions pro	ICND1 Chapter 08 - Op

Filter: All Questions

Figure 22-2. PCPT Grading Results Page

To perform the process of reviewing questions and marking them as complete, you can move between this Question Review page and the individual questions. Just double-click a question to move back to that question. From the question, click **Grade Exam** to move back to the grading results, and to the Question Review page shown in Figure 22-2. The question window also shows the place to mark the question, in the upper left, as shown in Figure 22-3.


Pearson IT Certification Practice Test
File
Help
10.1.1.2
255.255.255.0
PC2
10.1.1.200
255.255.255.0
SW2
10.1.1.254
255.255.255.0
R1
S0/0
Console 0
10.1.1.1
255.255.255.0
PC1
SW1
10.1.1.199
255.255.255.0
Serial Port
PC3
Home
Send Feedback
Prev
Next
Reset
Notes
Answer
Exhibits
Grade Exam

☑ Mark Question 3 of 139

In the figure, the 2960 switches have been taken out of the box and cabled, and PC2 can communicate through R1 with the rest of the IP network. However, no configuration has been added to either SW1 or SW2. As a result, the network engineers sitting at a management station to the right of R1 cannot ping or telnet to SW2. Which of the following configuration commands, when entered in the correct order on SW2, allow the network engineer to ping or telnet to SW2 from the management station?

☐ A. **ip default-gateway 10.1.1.255**

Exam: CCENT/CCNA ICND1 640-822 Official Cert Guide; Question Id: SE-I1-822-09-003

Figure 22-3. Reviewing a Question, with the Mark Feature in the Upper Left

If you want to come back later, to look through the questions you missed from an earlier exam, start at the PCPT home screen. From there, instead of clicking the Start button to start a new exam, click the **View Grade History** button to see your earlier exam attempts and work through any missed questions.

Track your progress through your gap review in Table 22-6. PCPT lists your previous practice exams by date and score, so it helps to note those values in the table for comparison to the PCPT menu.

Table 22-6. Tracking Checklist for Gap Review of Practice Exams

Exam (ICND1, ICND2, or CCNA)	Original Practice Exam Date	Original Exam Score	Date Gap Review was Completed

Practice Hands-On CLI Skills

To do well on sim and simlet questions, you need to be comfortable with many Cisco router and switch commands, and how to use them from a Cisco command-line interface (CLI). As described in the Introduction to this book, sim questions require you to decide which configuration commands you need to configure to fix a problem or to complete a working configuration. Simlet questions require you to answer multiple choice questions by first using the CLI to issue **show** commands to look at the status of routers and switches in a small network.

To be ready for the exam, you need to know the following kinds of information:

- **CLI navigation:** Basic CLI mechanics of moving into and out of user, enable, and configuration modes
- **Individual configuration:** The meaning of the parameters of each configuration command
- **Feature configuration:** The set of configuration commands, both required and optional, for each feature
- **Verification of configuration:** The **show** commands that directly identify the configuration settings
- **Verification of status:** The **show** commands that list current status values

To help remember and review all this knowledge and skill, you can do the tasks listed in the next several pages.

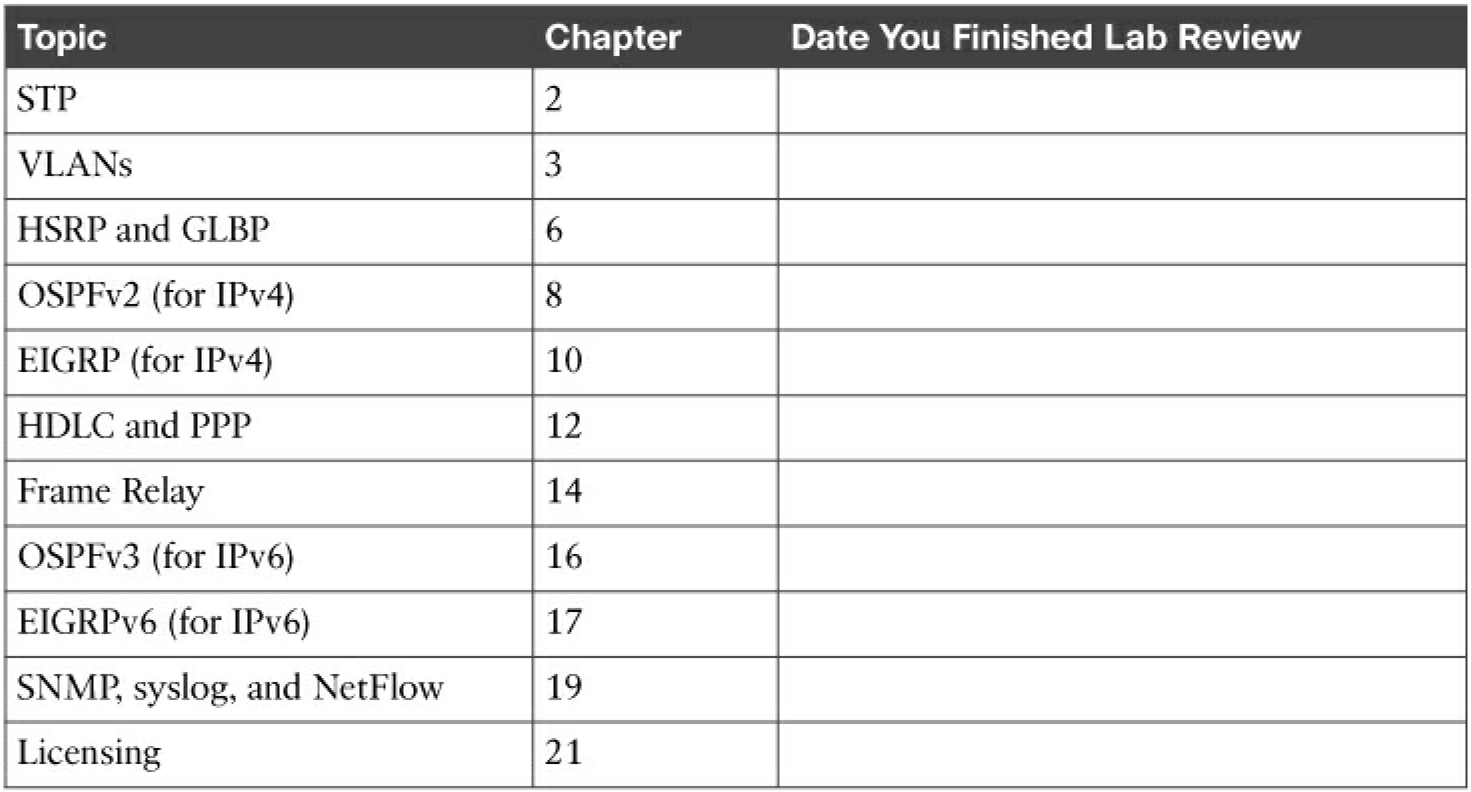
Review Mind Maps from Part Review

During Part Review, you created different mind maps with both configuration and verification commands. To remember the specific mind maps, flip back to each part's Part Review section.

Do Labs

Whatever method you chose for building hands-on CLI skills, take some time to review and do some labs to practice the commands. At this point, you should have thought about configuration quite a bit, whether in a simulator, real gear, or even just as paper exercises. Although it might be impractical to repeat every lab, make it a point to practice any commands and features for which you feel a little unsure about the topics from your review of the mind maps. Make sure to review lab exercises on the major topics in Table 22-7.

Table 22-7. Lab Checklist



Topic	Chapter	Date You Finished Lab Review
STP	2	
VLANs	3	
HSRP and GLBP	6	
OSPFv2 (for IPv4)	8	
EIGRP (for IPv4)	10	
HDLC and PPP	12	
Frame Relay	14	
OSPFv3 (for IPv6)	16	
EIGRPv6 (for IPv6)	17	
SNMP, syslog, and NetFlow	19	
Licensing	21	

One great way to practice is to use the Pearson Network Simulator (the Sim) at http://pearsonitcertification.com/networksimulator.

As a free alternative, you can do some short 5-to 10-minute paper configuration labs listed on the author's blogs. Just browse the Config Museum labs in those blogs (one blog for ICND1 and one for ICND2) and choose the labs you want to use. You can try these on paper or on your own lab gear. To find the blogs, start at www.certskills.com/blogs.

Other Study Tasks

If you get to this point and still feel the need to prepare some more, this last topic gives you three suggestions.

First, the Chapter Review exam preparation tasks and Part Review sections give you some useful study tasks.

Second, take more exam questions from other sources. You can always get more questions in the Cisco Press Premium Edition eBook and Practice Test products, which include an eBook copy of this book plus additional questions in additional PCPT exam banks. However, you can search the Internet for questions from many sources and review those questions as well.

Note

Some vendors claim to sell practice exams that contain the literal exam questions from the exam. These exams, called *brain dumps*, are against Cisco's testing policies. Cisco strongly discourages using any such tools for study.

Finally, join in the discussions on the Cisco Learning Network. Try to answer questions asked by other learners; the process of answering makes you think much harder about the topic. When someone posts an answer with which you disagree, think about why, and talk about it online. This is a great way to both learn more and build confidence.

Final Thoughts

You have studied quite a bit, worked hard, and sacrificed time and money to be ready for the exam. I hope your exam goes well, that you pass, and that you pass because you really know your stuff and will do well in your IT and networking career.

I encourage you to celebrate when you pass and to ask advice when you do not. The Cisco Learning Network is a great place to make posts to celebrate and to ask advice for the next time around. I personally would love to hear about your progress through Twitter (@wendellodom) or my Facebook fan page (http://facebook.com/wendellodom). I wish you well, and congratulations for working through the entire book!

Part VIII: Appendixes

Appendix A: Numeric Reference Tables

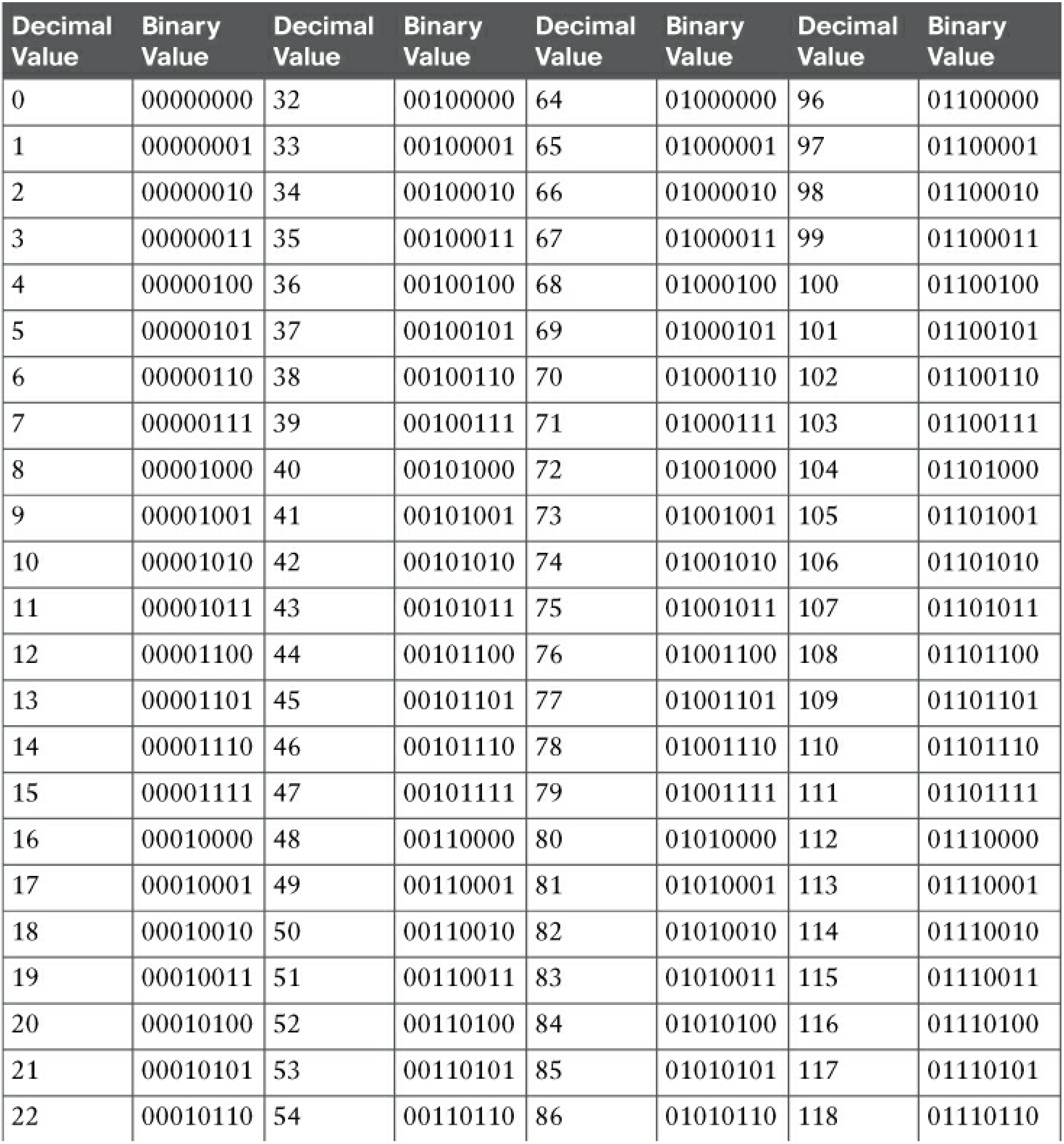
Appendix B: ICND2 Exam Updates

Glossary

Appendix A. Numeric Reference Tables

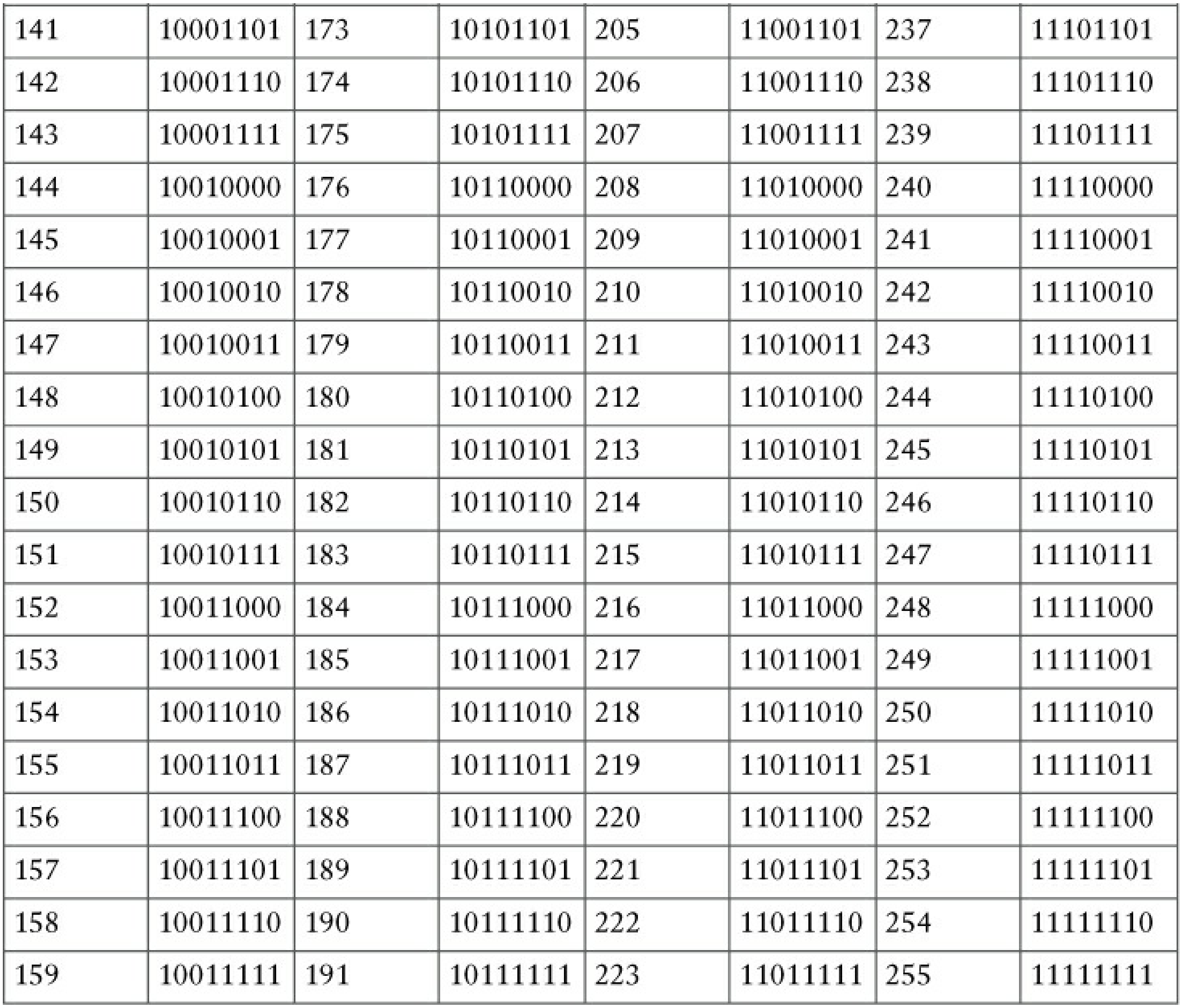
This appendix provides several useful reference tables that list numbers used throughout this book. Specifically: Table A-1: A decimal-binary cross reference, useful when converting from decimal to binary and vice versa.

Table A-1. Decimal-Binary Cross Reference, Decimal Values 0–255



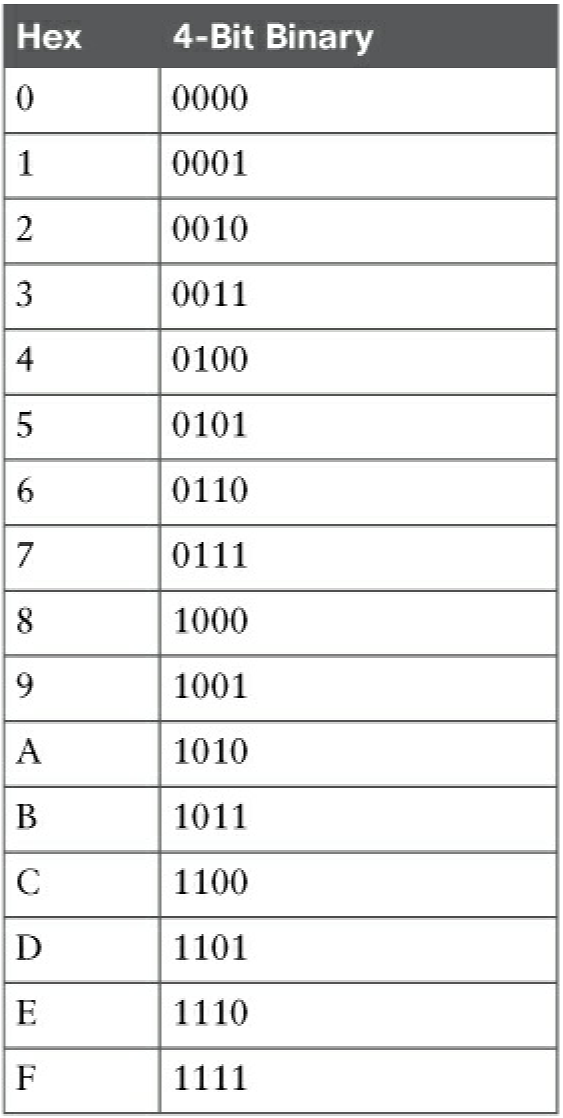
Decimal Value	Binary Value	Decimal Value	Binary Value	Decimal Value	Binary Value	Decimal Value	Binary Value
0	00000000	32	00100000	64	01000000	96	01100000
1	00000001	33	00100001	65	01000001	97	01100001
2	00000010	34	00100010	66	01000010	98	01100010
3	00000011	35	00100011	67	01000011	99	01100011
4	00000100	36	00100100	68	01000100	100	01100100
5	00000101	37	00100101	69	01000101	101	01100101
6	00000110	38	00100110	70	01000110	102	01100110
7	00000111	39	00100111	71	01000111	103	01100111
8	00001000	40	00101000	72	01001000	104	01101000
9	00001001	41	00101001	73	01001001	105	01101001
10	00001010	42	00101010	74	01001010	106	01101010
11	00001011	43	00101011	75	01001011	107	01101011
12	00001100	44	00101100	76	01001100	108	01101100
13	00001101	45	00101101	77	01001101	109	01101101
14	00001110	46	00101110	78	01001110	110	01101110
15	00001111	47	00101111	79	01001111	111	01101111
16	00010000	48	00110000	80	01010000	112	01110000
17	00010001	49	00110001	81	01010001	113	01110001
18	00010010	50	00110010	82	01010010	114	01110010
19	00010011	51	00110011	83	01010011	115	01110011
20	00010100	52	00110100	84	01010100	116	01110100
21	00010101	53	00110101	85	01010101	117	01110101
22	00010110	54	00110110	86	01010110	118	01110110

23	00010111	55	00110111	87	01010111	119	01110111
24	00011000	56	00111000	88	01011000	120	01111000
25	00011001	57	00111001	89	01011001	121	01111001
26	00011010	58	00111010	90	01011010	122	01111010
27	00011011	59	00111011	91	01011011	123	01111011
28	00011100	60	00111100	92	01011100	124	01111100
29	00011101	61	00111101	93	01011101	125	01111101
30	00011110	62	00111110	94	01011110	126	01111110
31	00011111	63	00111111	95	01011111	127	01111111
128	10000000	160	10100000	192	11000000	224	11100000
129	10000001	161	10100001	193	11000001	225	11100001
130	10000010	162	10100010	194	11000010	226	11100010
131	10000011	163	10100011	195	11000011	227	11100011
132	10000100	164	10100100	196	11000100	228	11100100
133	10000101	165	10100101	197	11000101	229	11100101
134	10000110	166	10100110	198	11000110	230	11100110
135	10000111	167	10100111	199	11000111	231	11100111
136	10001000	168	10101000	200	11001000	232	11101000
137	10001001	169	10101001	201	11001001	233	11101001
138	10001010	170	10101010	202	11001010	234	11101010
139	10001011	171	10101011	203	11001011	235	11101011
140	10001100	172	10101100	204	11001100	236	11101100



141	10001101	173	10101101	205	11001101	237	11101101
142	10001110	174	10101110	206	11001110	238	11101110
143	10001111	175	10101111	207	11001111	239	11101111
144	10010000	176	10110000	208	11010000	240	11110000
145	10010001	177	10110001	209	11010001	241	11110001
146	10010010	178	10110010	210	11010010	242	11110010
147	10010011	179	10110011	211	11010011	243	11110011
148	10010100	180	10110100	212	11010100	244	11110100
149	10010101	181	10110101	213	11010101	245	11110101
150	10010110	182	10110110	214	11010110	246	11110110
151	10010111	183	10110111	215	11010111	247	11110111
152	10011000	184	10111000	216	11011000	248	11111000
153	10011001	185	10111001	217	11011001	249	11111001
154	10011010	186	10111010	218	11011010	250	11111010
155	10011011	187	10111011	219	11011011	251	11111011
156	10011100	188	10111100	220	11011100	252	11111100
157	10011101	189	10111101	221	11011101	253	11111101
158	10011110	190	10111110	222	11011110	254	11111110
159	10011111	191	10111111	223	11011111	255	11111111

Table A-2: A hexadecimal-binary cross reference, useful when converting from hex to binary and vice versa.

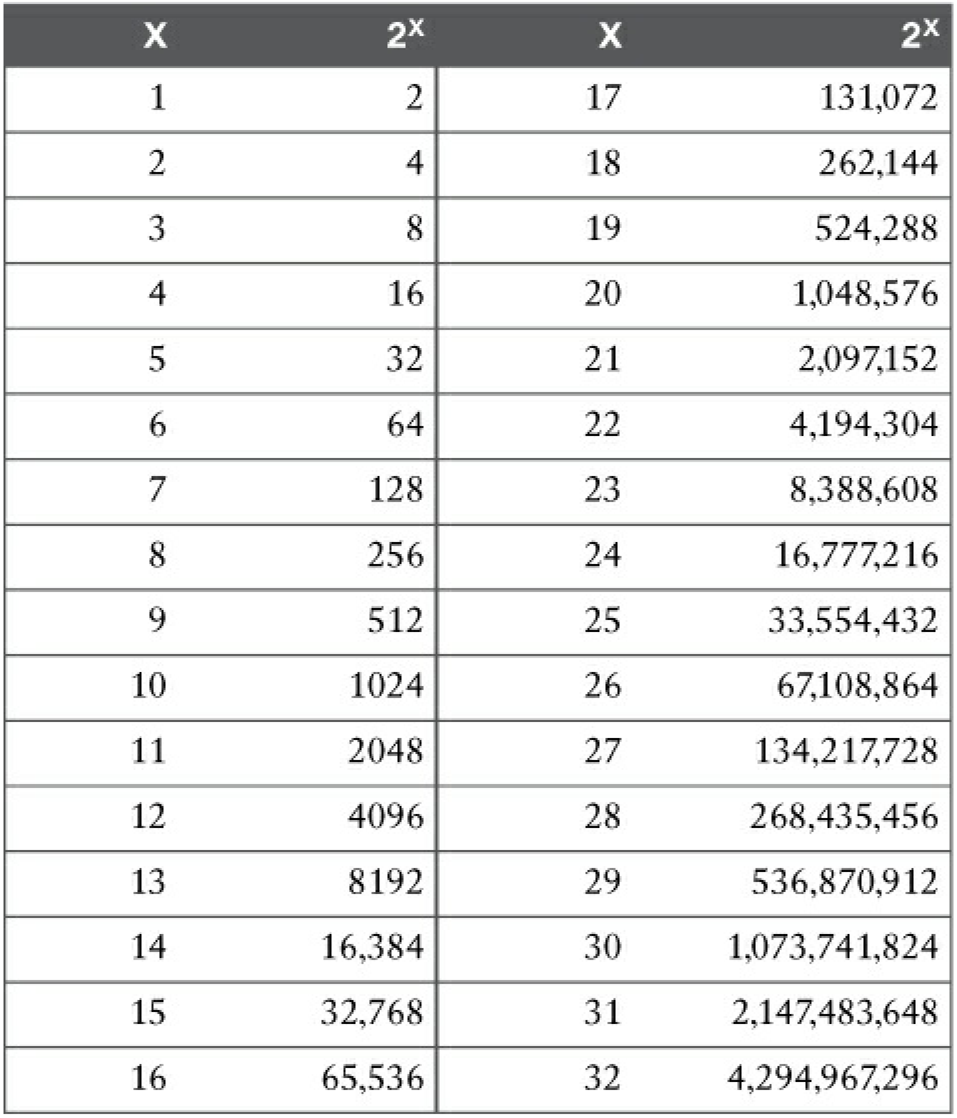


Hex	4-Bit Binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
A	1010
B	1011
C	1100
D	1101
E	1110
F	1111

Table A-2. Hex-Binary Cross Reference

Table A-3: Powers of 2, from 2^1 through 2^{32}.

Table A-3. Powers of 2



X	2^X	X	2^X
1	2	17	131,072
2	4	18	262,144
3	8	19	524,288
4	16	20	1,048,576
5	32	21	2,097,152
6	64	22	4,194,304
7	128	23	8,388,608
8	256	24	16,777,216
9	512	25	33,554,432
10	1024	26	67,108,864
11	2048	27	134,217,728
12	4096	28	268,435,456
13	8192	29	536,870,912
14	16,384	30	1,073,741,824
15	32,768	31	2,147,483,648
16	65,536	32	4,294,967,296

Table A-4: Table of all 33 possible subnet masks, in all three formats.

Table A-4. All Subnet Masks

Decimal	Prefix	Binary
0.0.0.0	/0	00000000 00000000 00000000 00000000
128.0.0.0	/1	10000000 00000000 00000000 00000000
192.0.0.0	/2	11000000 00000000 00000000 00000000
224.0.0.0	/3	11100000 00000000 00000000 00000000
240.0.0.0	/4	11110000 00000000 00000000 00000000
248.0.0.0	/5	11111000 00000000 00000000 00000000
252.0.0.0	/6	11111100 00000000 00000000 00000000
254.0.0.0	/7	11111110 00000000 00000000 00000000
255.0.0.0	/8	11111111 00000000 00000000 00000000
255.128.0.0	/9	11111111 10000000 00000000 00000000
255.192.0.0	/10	11111111 11000000 00000000 00000000
255.224.0.0	/11	11111111 11100000 00000000 00000000
255.240.0.0	/12	11111111 11110000 00000000 00000000
255.248.0.0	/13	11111111 11111000 00000000 00000000
255.252.0.0	/14	11111111 11111100 00000000 00000000
255.254.0.0	/15	11111111 11111110 00000000 00000000
255.255.0.0	/16	11111111 11111111 00000000 00000000
255.255.128.0	/17	11111111 11111111 10000000 00000000
255.255.192.0	/18	11111111 11111111 11000000 00000000
255.255.224.0	/19	11111111 11111111 11100000 00000000
255.255.240.0	/20	11111111 11111111 11110000 00000000
255.255.248.0	/21	11111111 11111111 11111000 00000000
255.255.252.0	/22	11111111 11111111 11111100 00000000
255.255.254.0	/23	11111111 11111111 11111110 00000000
255.255.255.0	/24	11111111 11111111 11111111 00000000
255.255.255.128	/25	11111111 11111111 11111111 10000000
255.255.255.192	/26	11111111 11111111 11111111 11000000
255.255.255.224	/27	11111111 11111111 11111111 11100000
255.255.255.240	/28	11111111 11111111 11111111 11110000
255.255.255.248	/29	11111111 11111111 11111111 11111000
255.255.255.252	/30	11111111 11111111 11111111 11111100
255.255.255.254	/31	11111111 11111111 11111111 11111110
255.255.255.255	/32	11111111 11111111 11111111 11111111

Appendix B. ICND2 Exam Updates

Over time, reader feedback allows Cisco Press to gauge which topics give our readers the most problems when taking the exams. In addition, Cisco may make small changes in the breadth of exam topics or in emphasis of certain topics. To assist readers with those topics, the author creates new materials clarifying and expanding on those troublesome exam topics.

The document you are viewing is Version 1.0 of this appendix, and there are no updates. You can check for an updated version at http://www.ciscopress.com/title/9781587143731.

Glossary

2-way state

In OSPF, a neighbor state that implies that the router has exchanged Hellos with the neighbor and that all required parameters match.

3G/4G Internet

An Internet access technology that uses wireless radio signals to communicate through mobile phone towers, most often used by mobile phones, tablets, and some other mobile devices.

A

ABR

Area Border Router. A router using OSPF in which the router has interfaces in multiple OSPF areas.

access link

In Frame Relay, the physical serial link that connects a Frame Relay DTE, usually a router, to a Frame Relay switch. The access link uses the same physical layer standards as do point-to-point leased lines.

access rate

In Frame Relay, the speed at which bits are sent over an access link.

ACL

Access control list. A list configured on a router to control packet flow through the router, such as to prevent packets with a certain IP address from leaving a particular interface on the router.

Active Virtual Gateway (AVG)

With Gateway Load Balancing Protocol (GLBP), the function by which a router answers ARP requests for the virtual IP address, replying with different virtual MAC addresses for the purpose of load balancing user traffic on a per-host basis.

administrative distance

In Cisco routers, a means for one router to choose between multiple routes to reach the same subnet when those routes are learned by different routing protocols. The lower the administrative distance, the more preferred the source of the routing information.

administrative mode

See trunking administrative mode.

ADSL

Asymmetric digital subscriber line. One of many DSL technologies, ADSL is designed to deliver more bandwidth downstream (from the central office to the customer site) than upstream.

analog modem

See modem.

AR

See access rate.

Area Border Router

See ABR.

ARP

Address Resolution Protocol. An Internet protocol used to map an IP address to a MAC address. Defined in RFC 826.

ASBR

Autonomous System Border Router. A router using OSPF in which the router learns routes via another source, usually another routing protocol, exchanging routes that are external to OSPF with the OSPF domain.

authentication

Authentication is the ability to verify the identity of a user or a computer system on a computer network.

Autonomous System Border Router

See ASBR.

autonomous system number (ASN)

A number used by BGP to identify a routing domain, often a single enterprise or organization. Within the context of this book, as used with EIGRP, a number that identifies the routing processes on routers that are willing to exchange EIGRP routing information with each other.

autosummarization

A routing protocol feature in which a router that connects to more than one classful network advertises summarized routes for each entire classful network when sending updates out interfaces connected to other classful networks.

autosummary

See autosummarization.

B

backbone area

In OSPFv2 and OSPFv3, the special area in a multi-area design, with all nonbackbone areas needing to connect to the backbone area. area 0.

backup designated router

An OSPF router connected to a multiaccess network that monitors the work of the designated router (DR) and takes over the work of the DR if the DR fails.

balanced hybrid

A term referencing the combination of distance vector and link state features as implemented by EIGRP.

blocking state

In 802.1D STP, a port state in which no received frames are processed and the switch forwards no frames out the interface, with the exception of STP messages.

boot field

The low-order 4 bits of the configuration register in a Cisco router. The value in the boot field in part tells the router where to look for a Cisco IOS image to load.

BPDU

Bridge protocol data unit. The generic name for Spanning Tree Protocol messages.

BPDU Guard

A Cisco switch feature that listens for incoming STP BPDU messages, disabling the interface if any are received. The goal is to prevent loops when a switch connects to a port expected to only have a host connected to it.

BRI

Basic Rate Interface. An ISDN interface composed of two bearer channels and one data (D) channel for circuit-switched communication of voice, video, and data.

bridge ID (BID)

An 8-byte identifier for bridges and switches used by STP and RSTP. It is composed of a 2-byte priority field followed by a 6-byte System ID field that is usually filled with a MAC address.

bridge protocol data unit

See BPDU.

broadcast address

See subnet broadcast address.

broadcast domain

A set of all devices that receive broadcast frames originating from any device in the set. Devices in the same VLAN are in the same broadcast domain.

broadcast subnet

When subnetting a Class A, B, or C network, the one subnet in each classful network for which all subnet bits have a value of binary 1. The subnet broadcast address in this subnet has the same numeric value as the classful network's networkwide broadcast address.

C

cable Internet

An Internet access technology that uses a cable TV (CATV) cable, normally used for video, to send and receive data.

CHAP

Challenge Handshake Authentication Protocol. A security feature defined by PPP that allows either or both endpoints on a link to authenticate the other device as a particular authorized device.

CIDR

Classless interdomain routing. An RFC-standard tool for global IP address range assignment. CIDR reduces the size of Internet routers' IP routing tables, helping deal with the rapid growth of the Internet. The term *classless* refers to the fact that the summarized groups of networks represent a group of addresses that do not confirm to IPv4 classful (Class A, B, and C) grouping rules.

CIDR notation

See prefix notation.

circuit switching

The switching system in which a dedicated physical circuit path must exist between the sender and the receiver for the duration of the "call." Used heavily in the telephone company network.

Cisco Prime

Cisco Prime is graphical user interface (GUI) software that utilizes SNMP and can be used to manage your Cisco network devices. The term *Cisco Prime* is an "umbrella" term that encompasses many different individual software products.

classful addressing

A concept in IPv4 addressing that defines a subnetted IP address as having three parts: network, subnet, and host.

classful network

An IPv4 Class A, B, or C network. It is called a classful network because these networks are defined by the class rules for IPv4 addressing.

classful routing protocol

An inherent characteristic of a routing protocol. Specifically, the routing protocol does not send subnet masks in its routing updates. This requires the protocol to make assumptions about classful networks and makes it unable to support VLSM and manual route summarization.

classless addressing

A concept in IPv4 addressing that defines a subnetted IP address as having two parts: a prefix (or subnet) and a host.

classless interdomain routing (CIDR)

See CIDR.

classless routing

A variation of the IPv4 forwarding (routing) process that defines the particulars of how the default route is used. The default route is always used for packets whose destination IP address does not match any other routes.

classless routing protocol

An inherent characteristic of a routing protocol. Specifically, the routing protocol sends subnet masks in its routing updates, thereby removing any need to make assumptions about the addresses in a particular subnet or network. This allows the protocol to support VLSM and manual route summarization.

composite metric

A term in EIGRP for the result of the calculation of the EIGRP metric for a route.

configuration register

In Cisco routers, a 16-bit user-configurable value that determines how the router functions during initialization. In software, the bit position is set by specifying a hexadecimal value using configuration commands.

contiguous network

In IPv4, a internetwork design in which packets being forwarded between any two subnets of a single classful network only pass through the subnets of that classful network.

console port

A physical socket on a router or switch to which a cable can be connected between a computer and the router/switch, for the purpose of allowing the computer to use a terminal emulator and use the CLI to configure, verify, and troubleshoot the router/switch.

convergence

The time required for routing protocols to react to changes in the network, removing bad routes and adding new, better routes so that the current best routes are in all the routers' routing tables.

CSU/DSU

Channel service unit/data service unit. A device that connects a physical circuit installed by the telco to some CPE device, adapting between the voltages, current, framing, and connectors used on the circuit to the physical interface supported by the DTE.

customer premise equipment (CPE)

A telco term that refers to equipment on-site at the telco customer site (the enterprise's site) that connects to the WAN service provided by the telco.

D

Database Description

An OSPF packet type that lists brief descriptions of the LSAs in the OSPF LSDB.

data link connection identifier (DLCI)

See DLCI.

DCE

Data circuit-terminating equipment. Also refers to data communications equipment. From a physical layer perspective, the device providing the clocking on a WAN link, usually a CSU/DSU, is the DCE. From a packet-switching perspective, the service provider's switch, to which a router might connect, is considered the DCE.

Dead Interval

In OSPF, a timer used for each neighbor. A router considers the neighbor to have failed if no Hellos are received from that neighbor in the time defined by the timer.

deencapsulation

On a computer that receives data over a network, the process in which the device interprets the lower-layer headers and, when finished with each header, removes the header, revealing the next-higher-layer PDU.

default gateway/default router

On an IP host, the IP address of some router to which the host sends packets when the packet's destination address is on a subnet other than the local subnet.

deny

An action taken with an ACL that implies that the packet is discarded.

designated port

In both STP and RSTP, a port role used to determine which of multiple interfaces on multiple switches, each connected to the same segment or collision domain, should forward frames to the segment. The switch advertising the lowest-cost Hello BPDU onto the segment becomes the DP.

designated router

In OSPF, on a multiaccess network, the router that wins an election and is therefore responsible for managing a streamlined process for exchanging OSPF topology information between all routers attached to that network.

dial access

A general term referring to any kind of switched WAN service that uses the telco network in which the device must signal (the equivalent of tapping digits on a phone) to establish a connection before sending data.

Diffusing Update Algorithm (DUAL)

A convergence algorithm used in EIGRP when a route fails and a router does not have a feasible successor route. DUAL causes the routers to send EIGRP Query and Reply messages to discover alternate loop-free routes.

Dijkstra Shortest Path First (SPF) algorithm

The name of the algorithm used by link-state routing protocols to analyze the LSDB and find the least-cost routes from that router to each subnet.

directed broadcast address

The same as a subnet broadcast address.

disabled port

In STP, a port role for nonworking interfaces—in other words, interfaces that are not in a connect or up/up interface state.

discarding state

An RSTP interface state in which no received frames are processed and the switch forwards no frames out the interface, with the exception of RSTP messages.

discontiguous network

In IPv4, a internetwork design in which packets being forwarded between two subnets of a single classful network must pass through the subnets of another classful network.

distance vector

The logic behind the behavior of some interior routing protocols, such as RIP and IGRP. Distance vector routing algorithms call for each router to send its entire routing table in each update, but only to its neighbors. Distance vector routing algorithms can be prone to routing loops but are computationally simpler than link-state routing algorithms. Also called Bellman-Ford routing algorithm.

DLCI

Data link connection identifier. The Frame Relay address that identifies a VC on a particular access link.

DNS

Domain Name System. An application layer protocol used throughout the Internet for translating hostnames into their associated IP addresses.

DS0

Digital signal level 0. A 64-Kbps line or channel of a faster line inside a telco whose origins are to support a single voice call using the original voice (PCM) codecs.

DS1

Digital signal level 1. A 1.544-Mbps line from the telco, with 24 DS0 channels of 64 Kbps each, plus an 8-Kbps management and framing channel. Also called a T1.

DS3

Digital signal level 3. A 44.736-Mbps line from the telco, with 28 DS1 channels plus overhead. Also called a T3.

DSL

Digital subscriber line. Public network technology that delivers high bandwidth over conventional telco local-loop copper wiring at limited distances. Usually used as an Internet access technology connecting a user to an ISP.

DSL modem

A device that connects to a telephone line and uses DSL standards to transmit and receive data to/from a telco using DSL.

DTE

Data terminal equipment. From a Layer 1 perspective, the DTE synchronizes its clock based on the clock sent by the DCE. From a packet-switching perspective, the DTE is the device outside the service provider’s network, usually a router.

DUAL

See Diffusing Update Algorithm.

dual stacks

In IPv6, a mode of operation in which a host or router runs both IPv4 and IPv6.

E

EIGRP

Enhanced Interior Gateway Routing Protocol. An advanced version of IGRP developed by Cisco. Provides superior convergence properties and operating efficiency and combines the advantages of link-state protocols with those of distance vector protocols.

EIGRPv6

EIGRP for IPv6. A version of EIGRP that supports advertising routes for IPv6 prefixes instead of IPv4 subnets.

enable mode

A part of the Cisco IOS CLI in which the user can use potentially disruptive commands on a router or switch, including the ability to then reach configuration mode and reconfigure the router.

encapsulation

The placement of data from a higher-layer protocol behind the header (and in some cases, between a header and trailer) of the next-lower-layer protocol. For example, an IP packet could be encapsulated in an Ethernet header and trailer before being sent over an Ethernet.

encoding

The conventions for how a device varies the electrical or optical signals sent over a cable to imply a particular binary code. For instance, a modem might encode a binary 1 or 0 by using one frequency to mean 1 and another to mean 0.

encryption

Encryption is the ability to take data and send the data in a form that is not readable by someone that intercepts this data.

EtherChannel

A feature in which up to eight parallel Ethernet segments between the same two devices, each using the same speed, can be combined to act as a single link for forwarding and Spanning Tree Protocol logic.

Ethernet WAN

Any WAN service that happens to use any type of Ethernet link as the access link between the customer and the WAN service.

EUI-64

Literally, a standard for an extended unique identifier that is 64 bits long. Specifically for IPv6, a set of rules for forming a 64-bit identifier, used as the interface ID in IPv6 addresses, by starting with a 48-bit MAC address, inserting FFFE (hex) in the middle, and inverting the seventh bit.

extended access list

A list of IOS **access-list** global configuration commands that can match multiple parts of an IP packet, including the source and destination IP address and TCP/UDP ports, for the purpose of deciding which packets to discard and which to allow through the router.

extended ping

An IOS command in which the **ping** command accepts many other options besides just the destination IP address.

F

feasibility condition

In EIGRP, when a router has learned of multiple routes to reach one subnet, if the best route’s metric is X, the feasibility condition is another route whose reported distance is < X.

feasible distance

In EIGRP, the metric of the best route to reach a subnet.

feasible successor

In EIGRP, a route that is not the best route (successor route) but that can be used immediately if the best route fails, without causing a loop. Such a route meets the feasibility condition.

FTP

File Transfer Protocol. An application protocol, part of the TCP/IP protocol stack, used to transfer files between network nodes. FTP is defined in RFC 959.

filter

Generally, a process or a device that screens network traffic for certain characteristics, such as source address, destination address, or protocol. This process determines whether to forward or discard that traffic based on the established criteria.

First Hop Redundancy Protocol (FHRP)

A class of protocols that includes HSRP, VRRP, and GLBP, which allows multiple redundant routers on the same subnet to act as a single default router (first-hop router).

flash memory

A type of read/write permanent memory that retains its contents even with no power applied to the memory and that uses no moving parts, making the memory less likely to fail over time.

forward

To send a frame toward its ultimate destination by way of an internetworking device.

forward delay

An STP timer, defaulting to 15 seconds, used to dictate how long an interface stays in the listening state, and the time spent in learning state. Also called the forward delay timer.

forwarding state

An STP and RSTP port state in which an interface operates unrestricted by STP.

forward route

From one host's perspective, the route over which a packet travels from that host to some other host.

Frame Relay

An international standard data link protocol that defines the capabilities to create a frame-switched (packet-switched) service, allowing DTE devices (usually routers) to send data to many other devices using a single physical connection to the Frame Relay service.

Frame Relay DCE

The Frame Relay switch.

Frame Relay DTE

The customer device connected to a Frame Relay access link, usually a router.

Frame Relay mapping

The information that correlates, or maps, a Frame Relay DLCI to the Layer 3 address of the DTE on the other end of the VC identified by the local DLCI.

framing

The conventions for how Layer 2 interprets the bits sent according to OSI Layer 1. For example, after an electrical signal has been received and converted to binary, framing identifies the information fields inside the data.

full duplex

Generically, any communication in which two communicating devices can concurrently send and receive data. Specifically for Ethernet LANs, the ability of both devices to send and receive at the same time. This is allowed when there are only two stations in a collision domain. Full duplex is enabled by turning off the CSMA/CD collision detection logic.

full state

In OSPF, a neighbor state that implies that the two routers have exchanged the complete (full) contents of their respective LSDBs.

full update

With IP routing protocols, the general concept that a routing protocol update lists all known routes. *See also* partial update.

fully adjacent

In OSPF, a characterization of the state of a neighbor in which the two neighbors have reached the full state.

G

Gateway Load Balancing Protocol (GLBP)

A Cisco proprietary protocol that allows two (or more) routers to share the duties of being the default router on a subnet, with an active/active model, with all routers actively forwarding off-subnet traffic for some hosts in the subnet.

generic routing encapsulation (GRE)

A protocol, defined RFC 2784, that defines the headers used when creating a site-to-site VPN tunnel. The protocol defines the use of a normal IP header, called the Delivery Header, and a GRE header that the endpoints use to create and manage traffic over the GRE tunnel.

GET message

GET messages are used by SNMP to read from variable in the MIB.

GLBP active

A Gateway Load Balancing Protocol (GLBP) state in which the router serves as the Active Virtual Gateway (AVG), or, for a GLBP forwarder, a router that actively supports the forwarding of off-subnet packets for hosts in that subnet.

GLBP listen

A Gateway Load Balancing Protocol (GLBP) state for a forwarder in which the router does not currently support the forwarding of off-subnet packets for hosts in that subnet for a given virtual MAC address, instead waiting to take over that role for the currently-active forwarder.

GLBP standby

A Gateway Load Balancing Protocol (GLBP) state in which the router does not serve as the Active Virtual Gateway (AVG), but instead monitors the current AVG, and takes over for that AVG if it fails.

global routing prefix

An IPv6 prefix, which defines an IPv6 address block made up of global unicast addresses, assigned to one organization, so that that organization has a block of globally unique IPv6 addresses to use in their network.

global unicast address

A type of unicast IPv6 address that has been allocated from a range of public globally unique IP addresses as registered through IANA/ICANN, its member agencies, and other registries or ISPs.

GRE tunnel

A site-to-site VPN idea, in which the endpoints act as if a point-to-point link (the tunnel) exists between the sites, while actually encapsulating packets using GRE standards.

H

HDLC

High-Level Data Link Control. A bit-oriented synchronous data link layer protocol developed by the International Organization for Standardization (ISO). Derived from synchronous data link control (SDLC), HDLC specifies a data encapsulation method on synchronous serial links using frame characters and checksums.

Hello

(Multiple definitions) 1) A protocol used by OSPF routers to discover, establish, and maintain neighbor relationships. 2) A protocol used by EIGRP routers to discover, establish, and maintain neighbor relationships. 3) In STP, refers to the name of the periodic message sourced by the root bridge in a spanning tree.

hello BPDU

The STP and RSTP message used for the majority of STP communications, listing the root's bridge ID, the sending device's bridge ID, and the sending device's cost with which to reach the root.

Hello Interval

With OSPF and EIGRP, an interface timer that dictates how often the router should send Hello messages.

hello timer

In STP, the time interval at which the root switch should send hello BPDUs.

Hot Standby Router Protocol (HSRP)

A Cisco proprietary protocol that allows two (or more) routers to share the duties of being the default router on a subnet, with an active/standby model, with one router acting as the default router and the other sitting by waiting to take over that role if the first router fails.

HSRP active

A Hot Standby Router Protocol (HSRP) state in which the router actively supports the forwarding of off-subnet packets for hosts in that subnet.

HSRP standby

A Hot Standby Router Protocol (HSRP) state in which the router does not currently support the forwarding of off-subnet packets for hosts in that subnet, instead waiting for the currently active router to fail before taking over that role.

I

ICMP Echo Request

One type of ICMP message, created specifically to be used as the message sent by the **ping** command to test connectivity in a network. The **ping** command sends these messages to other hosts, expecting the other host to reply with an ICMP Echo Reply message.

ICMP Echo Reply

One type of ICMP message, created specifically to be used as the message sent by the **ping** command to test connectivity in a network. The **ping** command expects to receive these messages from other hosts, after the **ping** command first sends an ICMP Echo Request message to the host.

IEEE 802.11

The IEEE base standard for wireless LANs.

IEEE 802.1AD

The IEEE standard for the functional equivalent of the Cisco proprietary EtherChannel.

IEEE 802.1D

The IEEE standard for the original Spanning Tree Protocol.

IEEE 802.1Q

The IEEE-standard VLAN trunking protocol. 802.1Q includes the concept of a native VLAN, for which no VLAN header is added, and a 4-byte VLAN header is inserted after the original frame's type/length field.

IEEE 802.1W

The IEEE standard for Multiple Instances of Spanning Tree (MIST), which allows for load balancing of traffic among different VLANs.

IEEE 802.1W

The IEEE standard for an enhanced version of STP, called Rapid STP, which speeds convergence.

IEEE 802.3

The IEEE base standard for Ethernet-like LANs.

IGRP

Interior Gateway Routing Protocol. An old, no-longer-supported Interior Gateway Protocol (IGP) developed by Cisco.

inferior hello

When STP compares two or more received hello BPDUs, an inferior hello is a hello that lists a numerically larger root bridge ID than another hello or a hello that lists the same root Bridge ID but with a larger cost.

infinity

In the context of IP routing protocols, a finite metric value defined by the routing protocol that is used to represent an unusable route in a routing protocol update.

inform

The inform message is like a trap message in SNMP. This message is proactively generated by the managed device. This message is based on thresholds configured by a network administrator. The difference between an Inform and a trap is that an inform must be acknowledged by the network management station.

integrity

Integrity in data transfers means that the network administrator can determine that the information has not been tampered with in transit.

inter-area prefix LSA

In OSPFv6, a type of LSA similar to the Type 3 summary LSA in OSPFv2, created by an Area Border Router (ABR), to describe an IPv6 prefix one area in the database of another area.

interior gateway protocol (IGP)

A routing protocol designed to be used to exchange routing information inside a single autonomous system.

Inter-Switch Link (ISL)

The Cisco proprietary VLAN trunking protocol that predated 802.1Q by many years. ISL defines a 26-byte header that encapsulates the original Ethernet frame.

Internal router

In OSPF, a router with all interfaces in the same nonbackbone area.

Internetwork Operating System (IOS)

See IOS.

Inverse ARP

A Frame Relay protocol with which a router announces its Layer 3 address over a VC, thereby informing the neighbor of useful Layer 3-to-Layer 2 mapping information.

IOS

Cisco operating system software that provides the majority of a router’s or switch’s features, with the hardware providing the remaining features.

IOS feature set

A set of related features that can be enabled on a router to enable certain functionality. For example, the Security feature set would enable the ability to have the router act as a firewall in the network.

IOS image

A file that contains the IOS.

IP Control Protocol (IPCP)

A control protocol defined as part of PPP for the purpose of initializing and controlling the sending of IPv4 packets over a PPP link.

IPsec

The term referring to the IP Security protocols, which is an architecture for providing encryption and authentication services, usually when creating VPN services through an IP network.

ISDN

Integrated Services Digital Network. A communication protocol offered by telephone companies that permits telephone networks to carry data, voice, and video.

ISL

See Inter-Switch Link.

ISP prefix

In IPv6, the prefix that describes an address block that has been assigned to an ISP by some Internet registry.

K

keepalive

A feature of many data link protocols in which the router sends messages periodically to let the neighboring router know that the first router is still alive and well.

L

LAPF

Link Access Procedure Frame Bearer Services. Defines the basic Frame Relay header and trailer. The header includes DLCI, FECN, BECN, and DE bits.

learn

Switches learn MAC addresses by examining the source MAC addresses of frames they receive. They add each new MAC address, along with the port number of the port on which it learned of the MAC address, to an address table.

learning state

In STP, a temporary port state in which the interface does not forward frames, but it can begin to learn MAC addresses from frames received on the interface.

leased line

A transmission line reserved by a communications carrier for a customer's private use. A leased line is a type of dedicated line.

Link Control Protocol

A control protocol defined as part of PPP for the purpose of initializing and maintaining a PPP link.

link-local address

A type of unicast IPv6 address that represents an interface on a single data link. Packets sent to a link-local address cross only that particular link and are never forwarded to other subnets by a router. Used for communications that do not need to leave the local link, such as neighbor discovery.

link state

A classification of the underlying algorithm used in some routing protocols. Link-state protocols build a detailed database that lists links (subnets) and their state (up, down), from which the best routes can then be calculated.

link-state advertisement (LSA)

In OSPF, the name of the data structure that resides inside the LSDB and describes in detail the various components in a network, including routers and links (subnets).

link-state database (LSDB)

In OSPF, the data structure in RAM of a router that holds the various LSAs, with the collective LSAs representing the entire topology of the network.

link-state request

An OSPF packet used to ask a neighboring router to send a particular LSA.

link-state update

An OSPF packet used to send an LSA to a neighboring router.

listening state

A temporary STP port state that occurs immediately when a blocking interface must be moved to a forwarding state. The switch times out MAC table entries during this state. It also ignores frames received on the interface and doesn't forward any frames out the interface.

Local Management Interface (LMI)

A Frame Relay protocol used between a DTE (router) and DCE (Frame Relay switch). LMI acts as a keepalive mechanism. The absence of LMI messages means that the other device has failed. It also tells the DTE about the existence of each VC and DLCI, along with its status.

local username

A username (with matching password), configured on a router or switch. It is considered local because it exists on the router or switch, and not on a remote server.

LSA

See link-state advertisement.

M

MaxAge

In STP, a timer that states how long a switch should wait when it no longer receives hellos from the root switch before acting to reconverge the STP topology. Also called the MaxAge timer.

metric

A numeric measurement used by a routing protocol to determine how good a route is as compared to other alternate routes to reach the same subnet.

MIB

The Management Information Base is used in SNMP. This standard database structure exists on the managed device and contains the variables that can be read from and optionally written to in order to manage the device.

modem

Modulator-demodulator. A device that converts between digital and analog signals so that a computer may send data to another computer using analog telephone lines. At the source, a modem converts digital signals to a form suitable for transmission over analog communication facilities. At the destination, the analog signals are returned to their digital form.

MPLS

Multiprotocol Label Switching. Method of forwarding packets based on labels, instead of IP headers. Can be combined with other service provider features to provide WAN services to customers.

MTU

Maximum transmission unit. The maximum packet size, in bytes, that a particular interface can handle.

multi-area

In OSPFv2 and OSPFv3, a design that uses multiple areas.

N

NBMA

See nonbroadcast multiaccess.

neighbor

In routing protocols, another router with which a router decides to exchange routing information.

Neighbor Advertisement (NA)

A message defined by the IPv6 Neighbor Discovery Protocol (NDP) and used to declare to other neighbors a host’s MAC address. Sometimes sent in response to a previously-received NDP Neighbor Solicitation (NS) message.

Neighbor Discovery Protocol (NDP)

A protocol that is part of the IPv6 protocol suite and is used to discover and exchange information about devices on the same subnet (neighbors). In particular, it replaces IPv4 ARP.

Neighbor Solicitation (NS)

A message defined by the IPv6 Neighbor Discovery Protocol (NDP) and used to ask a neighbor to reply back with a Neighbor Advertisement, which lists the neighbor’s MAC address.

neighbor table

For OSPF and EIGRP, a list of routers that have reached neighbor status.

NetFlow

NetFlow permits the monitoring of IP traffic in your network. You can use this information for accounting, billing, capacity planning, security, and overall network monitoring.

Network LSA

In OSPF, a type of LSA that a designated router (DR) creates for the network (subnet) for which the DR is helping to distribute LSAs.

NMS

The Network Management Station is the device that runs network management software to manage network devices. SNMP is often the network management protocol used between the NMS and the managed device.

nonbroadcast multiaccess (NBMA)

A characterization of a type of Layer 2 network in which more than two devices connect to the network, but the network does not allow broadcast frames to be sent to all devices on the network.

NVRAM

Nonvolatile RAM. A type of random-access memory (RAM) that retains its contents when a unit is powered off.

O

OID

The object identifier is used to uniquely describe a MIB variable in the SNMP database. This is a numeric string that identifies the variable uniquely and also describes where the variable exists in the MIB tree structure.

OSPF

Open Shortest Path First. A popular link-state IGP that uses a link-state database and the Shortest Path First (SPF) algorithm to calculate the best routes to reach each known subnet.

out-of-band

Network management traffic is often sent out-of-band (OOB). This means the traffic does not share the same network paths with user data traffic.

overlapping subnets

An (incorrect) IP subnet design condition in which one subnet’s range of addresses includes addresses in the range of another subnet.

P

packet switching

A WAN service in which each DTE device connects to a telco using a single physical line, with the possibility of being able to forward traffic to all other sites connected to the same service. The telco switch makes the forwarding decision based on an address in the packet header.

PAP

Password Authentication Protocol. A PPP authentication protocol that allows PPP peers to authenticate one another.

partial mesh

A network topology in which more than two devices could physically communicate, but by choice, only a subset of the pairs of devices connected to the network are allowed to communicate directly.

partial update

With IP routing protocols, the general concept that a routing protocol update lists a subset of all known routes. *See also* full update.

periodic update

With routing protocols, the concept that the routing protocol advertises routes in a routing update on a regular periodic basis. This is typical of distance vector routing protocols.

permanent virtual circuit (PVC)

A preconfigured communications path between two Frame Relay DTEs, identified by a local DLCI on each Frame Relay access link, that provides the functional equivalent of a leased circuit but without a physical leased line for each VC.

permit

An action taken with an ACL that implies that the packet is allowed to proceed through the router and be forwarded.

ping

Packet Internet groper. An Internet Control Message Protocol (ICMP) echo message and its reply; ping often is used in IP networks to test the reachability of a network device.

port

(Multiple definitions) 1) In TCP and UDP, a number that is used to uniquely identify the application process that either sent (source port) or should receive (destination port) data. 2) In LAN switching, another term for switch interface.

PortFast

A switch STP feature in which a port is placed in an STP forwarding state as soon as the interface comes up, bypassing the listening and learning states. This feature is meant for ports connected to end-user devices.

PPP

Point-to-Point Protocol. A data link protocol that provides router-to-router and host-to-network connections over synchronous and asynchronous circuits.

PPP over Ethernet (PPPoE)

A specific protocol designed to encapsulate PPP frames inside Ethernet frames, for the purpose of delivering the PPP frames between two devices, effectively creating a point-to-point tunnel between the two devices.

prefix notation

A shorter way to write a subnet mask in which the number of binary 1s in the mask is simply written in decimal. For instance, /24 denotes the subnet mask with 24 binary 1 bits in the subnet mask. The number of bits of value binary 1 in the mask is considered to be the prefix.

PRI

Primary Rate Interface. An ISDN interface to primary rate access. Primary rate access consists of a single 64-Kbps D channel plus 23 (T1) or 30 (E1) B channels for voice or data.

private address

Several Class A, B, and C networks that are set aside for use inside private organizations. These addresses, as defined in RFC 1918, are not routable through the Internet.

private IP network

One of several classful IPv4 network numbers that will never be assigned for use in the Internet, meant for use inside a single enterprise.

private key

A secret value used in public/private key encryption systems. Either encrypts a value that can then be decrypted using the matching public key, or decrypts a value that was previously encrypted with the matching public key.

problem isolation

The part of the troubleshooting process in which the engineer attempts to rule out possible causes of the problem, narrowing the possible causes until the root cause of the problem can be identified.

product activation key (PAK)

The number assigned by Cisco, during the IOS licensing process, that gives a Cisco customer the right to enable an IOS feature set on one of that customer’s routers of a particular model series (chosen at the time the PAK was purchased).

protocol type

A field in the IP header that identifies the type of header that follows the IP header, usually a Layer 4 header, such as TCP or UDP. ACLs can examine the protocol type to match packets with a particular value in this header field.

public key

A publicly available value used in public/private key encryption systems. Either encrypts a value that can then be decrypted using the matching private key, or decrypts a value that was previously encrypted with the matching private key.

PVC

See permanent virtual circuit.

R

RAM

Random-access memory. A type of volatile memory that can be read and written by a microprocessor.

Rapid Spanning Tree Protocol (RSTP)

Defined in IEEE 802.1w. Defines an improved version of STP that converges much more quickly and consistently than STP (802.1d).

Regional Internet Registry (RIR)

The generic term for one of five current organizations that are responsible for assigning the public, globally unique IPv4 and IPv6 address space.

registry prefix

In IPv6, the prefix that describes a block of public, globally unique IPv6 addresses assigned to a Regional Internet Registry by ICANN.

reported distance

From one EIGRP router's perspective, the metric for a subnet as calculated on a neighboring router and reported in a routing update to the first router.

reverse route

From one host's perspective, for packets sent back to the host from another host, the route over which the packet travels.

RIP

Routing Information Protocol. An interior gateway protocol (IGP) that uses distance vector logic and router hop count as the metric. RIP Version 1 (RIP-1) has become unpopular. RIP Version 2 (RIP-2) provides more features, including support for VLSM.

ROM

Read-only memory. A type of nonvolatile memory that can be read but not written by the microprocessor.

ROMMON

A shorter name for ROM Monitor, which is a low-level operating system that can be loaded into Cisco routers for several seldom needed maintenance tasks, including password recovery and loading a new IOS when flash memory has been corrupted.

root bridge

See root switch.

root cost

The STP cost from a nonroot switch to reach the root switch, as the sum of all STP costs for all ports out which a frame would exit to reach the root.

root port

In STP, the one port on a nonroot switch in which the least-cost Hello is received. Switches put root ports in a forwarding state.

root switch

In STP, the switch that wins the election by virtue of having the lowest bridge ID, and, as a result, sends periodic hello BPDUs (default, 2 seconds).

routable protocol

See routed protocol.

routed protocol

A Layer 3 protocol that defines a packet that can be routed, such as IPv4 and IPv6.

router ID (RID)

In EIGRP and OSPF, a 32-bit number, written in dotted decimal, that uniquely identifies each router.

Router Advertisement (RA)

A message defined by the IPv6 Neighbor Discovery Protocol (NDP) and used by routers to announce their willingness to act as an IPv6 router on a link. These may be sent in response to a previously received NDP Router Solicitation (RS) message.

Router Solicitation (RS)

A message defined by the IPv6 Neighbor Discovery Protocol (NDP) and used to ask any routers on the link to reply, identifying the router, plus other configuration settings (prefixes and prefix lengths).

router LSA

In OSPF, a type of LSA that a router creates to describe itself.

route summarization

The process of combining multiple routes into a single advertised route, for the purpose of reducing the number of entries in routers' IP routing tables.

routing protocol

A set of messages and processes with which routers can exchange information about routes to reach subnets in a particular network. Examples of routing protocols include Enhanced Interior Gateway Routing Protocol (EIGRP), Open Shortest Path First (OSPF), and Routing Information Protocol (RIP).

RSTP

See Rapid Spanning Tree Protocol.

running-config file

In Cisco IOS switches and routers, the name of the file that resides in RAM memory and holds the device's currently used configuration.

S

secondary IP address

The second (or more) IP address configured on a router interface, using the **secondary** keyword on the **ip address** command.

Secure Sockets Layer (SSL)

A security protocol that is integrated into commonly used web browsers that provides encryption and authentication services between the browser and a website.

segment

(Multiple definitions) 1) In TCP, a term used to describe a TCP header and its encapsulated data (also called an L4PDU). 2) Also in TCP, the set of bytes formed when TCP breaks a large chunk of data given to it by the application layer into smaller pieces that fit into TCP segments. 3) In Ethernet, either a single Ethernet cable or a single collision domain (no matter how many cables are used).

serial cable

A type of cable with many different styles of connectors used to connect a router to an external CSU/DSU on a leased-line installation.

serial link

Another term for leased line.

SET message

SET messages are used in SNMP to set the value in variables of the MIB. These messages are the key to an administrator configuring the managed device using SNMP.

setup mode

An option on Cisco IOS switches and routers that prompts the user for basic configuration information, resulting in new running-config and startup-config files.

shared key

A reference to a security key whose value is known by both the sender and receiver.

shortest path first

The algorithm used by OSPF to find all possible routes, and then choose the route with the lowest metric for each subnet.

single point of failure

In a network, a single device or link for which, if it fails, causes an outage for a given population of users.

site prefix

In IPv6, the prefix that describes a public globally unique IPv6 address block that has been assigned to an end-user organization (for example, an Enterprise or government agency). The assignment usually is made by an ISP or Internet registry.

SLSM

Static-length subnet mask. The usage of the same subnet mask for all subnets of a single Class A, B, or C network.

SNMP

Simple Network Management Protocol is an Internet-standard protocol for managing devices on IP networks. Devices that usually support SNMP include routers, switches, and servers. It is used mostly in network management systems to monitor network-attached devices for conditions that warrant administrative attention. SNMP is a component of the Internet Protocol Suite as defined by the Internet Engineering Task Force (IETF). It consists of a set of standards for network management, including an application layer protocol, a database schema, and a set of data objects.

SNMP agent

The Simple Network Management Protocol agent resides on the managed device. This software processes the SNMP messages sent by the Network Management Station (NMS).

Spanning Tree Protocol (STP)

A protocol defined by IEEE standard 802.1D. Allows switches and bridges to create a redundant LAN, with the protocol dynamically causing some ports to block traffic, so that the bridge/switch forwarding logic will not cause frames to loop indefinitely around the LAN.

split horizon

A distant vector routing technique in which information about routes is prevented from exiting the router interface through which that information was received. Split-horizon updates are useful in preventing routing loops.

SSL

See Secure Sockets Layer.

standard access list

A list of IOS global configuration commands that can match only a packet's source IP address for the purpose of deciding which packets to discard and which to allow through the router.

startup-config file

In Cisco IOS switches and routers, the name of the file that resides in NVRAM memory and holds the device's configuration that will be loaded into RAM as the running-config file when the device is next reloaded or powered on.

stateful DHCP

A term used in IPv6 to contrast with stateless DHCP. Stateful DHCP keeps track of which clients have been assigned which IPv6 addresses (state information).

stateless address autoconfiguration (SLAAC)

A feature of IPv6 in which a host or router can be assigned an IPv6 unicast address without the need for a stateful DHCP server.

stateless DHCP

A term used in IPv6 to contrast with stateful DHCP. Stateless DHCP servers do not lease IPv6 addresses to clients. Instead, they supply other useful information, such as DNS server IP addresses, but with no need to track information about the clients (state information).

subinterface

One of the virtual interfaces on a single physical interface.

subnet

A subdivision of a Class A, B, or C network, as configured by a network administrator. Subnets allow a single Class A, B, or C network to be used and still allow for a large number of groups of IP addresses, as is required for efficient IP routing.

subnet broadcast address

A special address in each subnet—specifically, the largest numeric address in the subnet—designed so that packets sent to this address should be delivered to all hosts in that subnet.

subnet mask

A 32-bit number that describes the format of an IP address. It represents the combined network and subnet bits in the address with mask bit values of 1 and represents the host bits in the address with mask bit values of 0.

subnet prefix

In IPv6, a term for the prefix that is assigned to each data link, acting like a subnet in IPv4.

successor

In EIGRP, the route to reach a subnet that has the best metric and should be placed in the IP routing table.

summary LSA

In OSPFv2, a type of LSA, created by an Area Border Router (ABR), to describe a subnet in one area in the database of another area.

summary route

A route created via configuration commands to represent routes to one or more subnets with a single route, thereby reducing the size of the routing table.

switch

A network device that filters, forwards, and floods frames based on each frame's destination address. The switch operates at the data link layer of the Open System Interconnection (OSI) reference model.

synchronous

The imposition of time ordering on a bit stream. Practically, a device tries to use the same speed as another device on the other end of a serial link. However, by examining transitions between voltage states on the link, the device can notice slight variations in the speed on each end and can adjust its speed accordingly.

syslog

A syslog server takes system messages from network devices and stores these messages in a database. The syslog server also provides reporting capabilities on these system messages. Some can even respond to select system messages with certain actions such as emailing and paging.

T

T1

A line from the telco that allows transmission of data at 1.544 Mbps, with the capability to treat the line as 24 different 64-Kbps DS0 channels (plus 8 Kbps of overhead).

T3

A line from the telco that allows transmission of data at 44.736 Mbps, with the capability to treat the line as 28 different 1.544 Mbps DS1 (T1) channels, plus overhead.

telco

A common abbreviation for telephone company.

TFTP

Trivial File Transfer Protocol. An application protocol that allows files to be transferred from one computer to another over a network, but with only a few features, making the software require little storage space.

topology database

The structured data that describes the network topology to a routing protocol. Link-state and balanced hybrid routing protocols use topology tables, from which they build the entries in the routing table.

traceroute

A program available on many systems that traces the path that a packet takes to a destination. It is used mostly to debug routing problems between hosts.

trap

The trap is a message type in SNMP. This message is proactively generated by the managed device. This message is based on thresholds configured by a network administrator.

triggered update

A routing protocol feature in which the routing protocol does not wait for the next periodic update when something changes in the network, instead immediately sending a routing update.

trunk

In campus LANs, an Ethernet segment over which the devices add a VLAN header that identifies the VLAN in which the frame exists.

trunking

Also called VLAN trunking. A method (using either the Cisco ISL protocol or the IEEE 802.1Q protocol) to support multiple VLANs that have members on more than one switch.

trunking administrative mode

The configured trunking setting on a Cisco switch interface, as configured with the **switchport mode** command.

trunking operational mode

The current behavior of a Cisco switch interface for VLAN trunking.

U

unequal-cost load balancing

A concept in EIGRP by which a router adds multiple unequal cost (unequal metric) routes to the routing table, at the same time, allowing equal-metric routes to be used.

unique local address

A type of IPv6 unicast address meant as a replacement for IPv4 private addresses.

universal device identifier (UDI)

A number Cisco assigns to each router, for the purpose of uniquely identifying the router's type and unique serial number, for the purpose of allowing the IOS software licensing process to work.

universal image

The Cisco IOS universal image contains all feature sets for the specific device for which it was made. The administrator just needs to license and enable the specific features he or she desires.

update timer

The time interval that regulates how often a routing protocol sends its next periodic routing updates. Distance vector routing protocols send full routing updates every update interval.

V

variable-length subnet mask(ing)

See VLSM.

variance

IGRP and EIGRP compute their metrics, so the metrics for different routes to the same subnet seldom have the exact same value. The variance value is multiplied with the lower metric when multiple routes to the same subnet exist. If the product is larger than the metrics for other routes, the routes are considered to have "equal" metric, allowing multiple routes to be added to the routing table.

VC

Virtual circuit. A logical concept that represents the path that frames travel between DTEs. VCs are particularly useful when comparing Frame Relay to leased physical circuits.

virtual LAN (VLAN)

A group of devices connected to one or more switches that are grouped into a single broadcast domain through configuration. VLANs allow switch administrators to place the devices connected to the switches in separate VLANs without requiring separate physical switches. This creates design advantages of separating the traffic without the expense of buying additional hardware.

virtual private network (VPN)

A set of security protocols that, when implemented by two devices on either side of an unsecure network such as the Internet, can allow the devices to send data securely. VPNs provide privacy, device authentication, anti-replay services, and data integrity services.

Virtual Router Redundancy Protocol (VRRP)

A TCP/IP RFC protocol that allows two (or more) routers to share the duties of being the default router on a subnet, with an active/standby model, with one router acting as the default router and the other sitting by waiting to take over that role if the first router fails.

virtual IP address

For any FHRP protocol, an IP address that the FHRP shares between multiple routers so that these multiple routers appear as a single default router to hosts on that subnet.

virtual MAC address

For any FHRP protocol, a MAC address that the FHRP uses to receive frames from hosts.

VLAN

See virtual LAN.

VLAN Trunking Protocol (VTP)

A Cisco proprietary messaging protocol used between Cisco switches to communicate configuration information about the existence of VLANs, including the VLAN ID and VLAN name.

VLSM

Variable-length subnet mask(ing). The ability to specify a different subnet mask for the same Class A, B, or C network number on different subnets. VLSM can help optimize available address space.

VoIP

Voice over IP. The transport of voice traffic inside IP packets over an IP network.

VPN

See virtual private network.

VPN client

Software that resides on a PC, often a laptop, so that the host can implement the protocols required to be an endpoint of a VPN.

VSAT

A term referring to both a type of WAN that uses satellites, and the type of small dish antenna (very small aperture terminal) used to send and receive data through the satellite.

W

WAN link

Another term for leased line.

wildcard mask

The mask used in Cisco IOS ACL commands and OSPF and EIGRP **network** commands.

Z

zero subnet

For every classful IPv4 network that is subnetted, the one subnet whose subnet number has all binary 0s in the subnet part of the number. In decimal, the 0 subnet can be easily identified because it is the same number as the classful network number.

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DVD Appendixes

Appendix C. Answers to the "Do I Know This Already?" Quizzes

Chapter 1

1. A. The switch forwarding process considers MAC table entries for one VLAN only. That VLAN is based on the inbound interface, and for an access interface, that VLAN is the access VLAN assigned to the inbound interface. The VLAN is never determined by the outbound interface (F0/2 in this case). The native VLAN could not matter because the inbound interface was not a trunk.
2. C. This command lists the interface state as connected and the VLAN as VLAN 3. Based on these facts, plus that the incoming broadcast came in on VLAN 3, the frame should be forwarded out this port. However, STP may choose to place F0/11 in a blocking state, and that blocking state is not noted in the output of the **show interfaces status** command. So, the **show** command rules F0/11 in as a possible output interface, but the STP status must be examined to know if SW1 will or will not forward the frame.
3. A and B. Listening and learning are transitory port states, used only when moving from the blocking to the forwarding state. Discarding is not an 802.1D STP port state.
4. C and D. Listening and learning are transitory port states, used only when moving from the blocking to the forwarding state. Discarding is not an 802.1D STP port state. Forwarding and blocking are stable states.
5. C. The smallest numeric bridge ID wins the election.
6. B. Nonroot switches forward Hellos received from the root; the root sends these Hellos based on the root's configured Hello timer.
7. D. The PortFast feature allows STP to move a port from blocking to forwarding, without going through the interim listening and learning states. STP allows this exception when the link is known to have no switch on the other end of the link, removing the risk of a switching loop. BPDU Guard is a common feature to use at the same time as PortFast, because it watches for incoming bridge protocol data units (BPDUs), which should not happen on an access port, and prevents the loops from a rogue switch by disabling the port.

Chapter 2

1. B and C. You cannot set the system ID part of the bridge ID (BID). However, you can set the priority part of the BID, the first 16 bits, in two ways. One way sets it directly (**spanning-tree vlan priority**), whereas the other tells the switch to figure out a priority setting that either makes the switch root (**spanning-tree root primary**) or the backup (**spanning-tree root secondary**).
2. B. Cisco switches use the extended system ID format for BIDs by default, in which the priority field is broken down into a base priority value (32,768 in this case) plus the VLAN ID. The priority of this switch allows it to be capable of being the root switch, but the command output does not supply enough information to know whether this switch is currently root.
3. A and D. The **spanning-tree cost 19** command sets the cost for all VLANs on that interface unless the cost is set by a **spanning-tree cost** command that lists the VLAN ID. The two commands with a **port-cost** parameter are incorrect; the correct keyword is simply **cost**. Finally, Cisco switches choose the default cost based on the current speed, not the interface's fastest possible speed. So, this interface, running at 100 Mbps, already defaults to the IEEE default cost for 100 Mbps, or 19.
4. D. IOS uses the **channel-group** configuration command to create an EtherChannel. Then, the term *etherchannel* is used in the **show etherchannel** command, which displays the status of the channel. The output of this show command then names the channel a *PortChannel*. The only answer that is not used somewhere in IOS to describe this multilink channel is *Ethernet-Channel*.
5. B. The two interfaces default to a port cost of 19 (Fa0/13) and 4 (Gi0/1), making SW3's cost to reach the root 10 + 19 = 29 out Fa0/13 and 20 + 4 = 24 over Gi0/1. SW3 therefore chooses Gi0/1 as its root port. SW3 could then advertise a cost of 24 (cost to reach the root) Hello out Fa0/13, but it would be inferior to the Hello already being received on Fa0/13 (cost 10), so SW3 would not choose Fa0/13 as a designated port.
6. A and D. The **show spanning-tree root** command lists the BID of the root switch in each VLAN. If the local switch is not the root switch, it also lists the root port and the root cost. The **show spanning-tree** command lists the root cost in the first group of messages. The **show spanning-tree bridge** command does list useful information, just not the root cost; the other listed command is not a valid command.

Chapter 6

1. D. With this design, but no FHRP, host A can send packets off-subnet as long as connectivity exists from host A to R1. Similarly, host B can send packets off-subnet as long as host B has connectivity to router R2. Both routers can attach to the same LAN subnet, and basically ignore each other in relation to their roles as default router, because they do not use an FHRP option. When either router fails, the hosts using that router as default router have no means by which to fail over.
2. C. The use of an FHRP in this design purposefully allows either router to fail and still support off-subnet traffic from all hosts in the subnet. Both routers can attach to the same LAN subnet per IPv4 addressing rules.
3. A. HSRP and VRRP use an active/standby approach, with all default router traffic in one subnet flowing through a single router at a given point in time. GLBP uses an active/active approach, balancing the traffic across all the participating default routers (first hops). BFD is not an FHRP option. (BFD stands for bidirectional forwarding detection and is not within the scope of this book.)
4. C. HSRP, like VRRP and GLBP, use a virtual IP address. The virtual IP address comes from the same subnet as the

routers' LAN interfaces, but is a different IP address than the router addresses configured with the **ip address** interface subcommand. As a result, the hosts will not point to 10.1.19.1 or 10.1.19.2 in this design. The other wrong answer lists an idea of using Domain Name System (DNS) to direct hosts to the right default router; although this idea exists in some other forms of network load balancing, it is not a part of any of the three FHRP protocols.

5. B. The command, taken from R3, lists R3 as HSRP active. That means R3 currently takes on the role of the router with the virtual IP address, listed as 10.1.12.2. R3 will send back Address Resolution Protocol (ARP) Reply messages when hosts ARP looking for 10.1.12.2, and process packets sent to the matching virtual MAC address. The 10.1.12.1 IP address is the interface IP address of the other router in the HSRP group, the one that is standing by to take over for router R3. Finally, R3 does not configure the virtual IP address with the **ip address** *interface* command, but instead with the **standby** *group* **ip** *virtual-address* interface subcommand.
6. C. The active virtual gateway (AVG), a GLBP concept, load balances traffic by rotating its ARP Reply messages to list the MAC address of different routers. As a result, different hosts send their packets to different routers' MAC addresses, balancing the traffic on a per-host basis. This command lists AVG information with the first line of output beneath the headings, with the Active Router column identifying the current AVG by its interface IP address (or local, if the local router is the AVG). In this case, with an IP address listed, the output confirms that the local router (R3) is not the AVG but that some other router, with address 10.1.12.4, is acting as AVG.

Chapter 7

1. A. Extranet VPNs connect sites in different but cooperating companies. Remote-access VPNs provide access to individual users, usually from home or while traveling. The term *enterprise VPN* is not generally used to describe a type of VPN.
2. C. Antivirus software is an important security function, but it is not a function provided by the VPN itself.
3. B. IPsec provides confidentiality, data integrity, authentication, and anti-replay. Intrusion prevention generally refers to a security function in a network in which a device watches all flows in the network, watching for combinations of packet content that is true of known viruses, and then trying to prevent those viruses from propagating into the network.
4. B. The tunnel source and tunnel destination IP addresses are addresses in the IP network that sits between the two tunnel endpoint routers. This IP network may be large; it might even be the entire Internet. The addresses referenced by these commands are interface IP addresses on the routers; the tunnel interfaces have IP addresses from the networks outside the tunnel.
5. B. The routers treat the tunnel like a point-to-point link, with the two routers forming an Open Shortest Path First (OSPF) neighbor relationship over that link. The tunnel itself will likely use a subnet of class B network 172.16.0.0 in this case. Router A will learn about router B's LAN subnet 172.16.2.0/24, and router B will learn about router A's LAN subnet of 172.16.1.0/24. Finally, OSPFv2 will be enabled on the LAN interfaces and the tunnel interface, but not the Internet interfaces, so OSPFv2 will not advertise routes related to the 8.8.8.8 and 9.9.9.9 addresses.

Chapter 8

1. C. Only Area Border Routers (ABRs) create Type 3 LSAs, and R1 is identified as a router internal to area 51, so R1 is not an ABR. Internal routers can (actually must) create a Type 1 router LSA for themselves. Also, they create a Type 2 Network LSA if the router is a designated router (DR) and the DR forms at least one neighbor relationship.
2. C. The correct answer is the one advantage of using a single-area design. The three wrong answers are advantages of using a multi-area design, with all reasons being much more important with a larger internetwork.
3. B. Neighboring OSPF routers that complete the database exchange are considered fully adjacent and rest in a full neighbor state. The up/up and final states are not OSPF states at all. The 2-way state is either an interim state or a stable state between some routers on the same VLAN.
4. C. An ABR, by definition, connects to the backbone area plus one or more nonbackbone areas. To do so, the configuration enables OSPF so that at least one interface is in area 0 (backbone) and at least one interface is in some other area. For the incorrect answers, the **abr enable** command is imaginary. Routers internal to a nonbackbone area (which are therefore not ABRs) use OSPF **network** commands that all refer to the same nonbackbone area. Finally, two routers cannot become OSPF neighbors if their interfaces are in different areas.
5. B. SPF calculates the cost of a route as the sum of the OSPF interface costs for all outgoing interfaces in the route. The interface cost can be set directly (**ip ospf cost**), or IOS uses a default based on the reference bandwidth and the interface bandwidth. Delay is the only setting that does not influence OSPFv2 metric calculations.
6. D. The BDR designation on this line is for backup designated router (BDR). On this command, this notation means that the neighbor (2.2.2.2) is the BDR, not the local router on which the command was issued (R1 in this case).

Chapter 9

1. D. Split horizon causes a router to not advertise a route out of the same interface on which the router was learned. It also causes the router to not advertise about the connected route on an interface in updates sent out that interface.
2. D. Route poisoning means advertising the failed route with an "infinite" metric, as opposed to simply ceasing to advertise the route. Of the incorrect answers, SPF defines how link-state protocols calculate and choose routes; DUAL defines how EIGRP does some of its processing to find replacement routes; and split horizon limits what routes a router advertises to help avoid routing loops.
3. A. EIGRP separates the function of monitoring neighbor state into the Hello message process, relying on the receipt of a Hello message. If a router does not receive an EIGRP Hello within the configured EIGRP hold time, the local router believes the neighbor has failed.
4. A and B. EIGRP uses bandwidth and delay by default. Load and reliability can be added to the mix with configuration, but Cisco recommends against adding these to the metric calculation.

5. B. The feasible distance (FD) is, for all known routes to reach a subnet, the metric for the best of those routes. The best route is called the successor route, and it is added to the IP routing table.
6. C. A route's reported distance (RD) is the metric used by the neighbor that advertised the route. A router uses it to determine which routes meet the feasibility condition for whether the route can be a feasible successor route.

Chapter 10

1. A and C. The EIGRP **network** command supports a parameter of a classful network, enabling EIGRP on all interfaces in that classful network or an address and wildcard mask. In the latter case, interface IP addresses that match the configured address, when applying ACL-like logic with the wildcard mask, match the command.
2. C and D. The EIGRP **network 10.0.0.2 0.0.0.0** command exactly matches the interface with address 10.0.0.2 because of the wildcard mask, enabling EIGRP on that interface. The EIGRP ASN value must match on both routers. The **network 10.0.0.1 0.0.0.0** exactly matches the address on R1, but the **network** command needs to match addresses on the local router, and these commands should exist on router R2. The **network 10** command is syntactically incorrect; the entire classful network must be configured.
3. D. RIP uses R, and OSPF uses O, but EIGRP uses D. The letter E was already in use by an old (and no longer used) routing protocol, so Cisco chose to use nearby letter D for EIGRP.
4. C. The output from the **show ip eigrp neighbors** command lists EIGRP neighbors. The command lists only routers that have passed all EIGRP neighbor checks. The address column identifies the neighbor based on the neighbor's interface IP address on their common link, not based on the neighbor's EIGRP router ID.
5. C. The first number in parentheses is the computed metric for a route, and the second number is the reported distance (RD) for the route. The route through 10.1.6.3 is the successor route, because the first number in parenthesis on this line matches the feasible distance (FD) on the first line. For the other two routes, only the third route's RD is less than the feasible distance (the metric of the successor route), making this route, with next-hop address 10.1.5.4, a feasible successor route.
6. A. By definition, the successor route is the best route to reach a subnet, and is the one route EIGRP always puts in the IP routing table. So, the **show ip route eigrp** command lists this route, including the metric. The **show ip eigrp topology** command lists both successor and feasible successor routes, including their metrics. The **show ip eigrp interfaces** command does not list route information, and the **show ip eigrp database** command is not a valid IOS command.
7. B. The unequal-cost load-balancing features allow IOS to place multiple unequal-cost routes into the routing table. The restrictions are that the metric must be less than or equal to variance times the feasible distance (5 times 100 in this case), so three of the routes meet this requirement, ruling out the route with metric 550. This feature also allows only successor and feasible successor routes, ruling out the route with metric 450. Of the two routes that meet both requirements, the route with metric 350 has the highest metric, as requested in the question text.

Chapter 12

1. B. The four-wire circuit cable supplied by the telco connects to the device acting as the CSU/DSU. That can be an external CSU/DSU or a CSU/DSU integrated into a router serial interface card. LAN switches do not have serial interfaces, and router serial interfaces do not have transceivers.
2. B. The standard HDLC header does not include a Type field, which identifies the type of packet encapsulated inside the HDLC frame.
3. A and C. The **encapsulation hdlc** command sets the interface encapsulation (data-link protocol) to HDLC. In addition, because Cisco routers default to use the Cisco proprietary HDLC on serial interfaces, removing the use of PPP with the **no encapsulation ppp** command also works. The other two answers list commands that do not exist in IOS.
4. C. Of the possible answers, only PAP and CHAP are PPP authentication protocols. PAP sends the password as clear text between the two devices.
5. A and D. Both routers need an **encapsulation ppp** command, and both also need IP addresses before the ping will work. R1 does not need a **clock rate** command because R2 is connected to the DCE cable.
6. B and D. The output lists encapsulation PPP, meaning that it is configured to use PPP. The line and protocol status are both up, LCP is open, and both CDPCP and IPCP are open, meaning that IP and CDP packets can be sent over the link.
7. C and D. The question states a problem symptom with an interface state of line status up, and protocol status down. One incorrect answer refers to a physical layer problem, which usually results in a line status (first status code) value of down. Another incorrect answer mentions an IP address mismatch on the ends of a link; this mistake allows both the line and protocol status of the interface to reach an up state. The two correct answers result in the router having a line status of up, but a protocol status of down.

Chapter 13

1. C. The LMI manages the link between the DTE and the switch, including noticing when a virtual circuit (VC) comes up or goes down.
2. A and D. The DTE usually sits at the customer site, and the DCE sits at the service provider site. Frame Relay switches send LMI messages to DTEs (usually routers) to signal VC status. A Frame Relay frame does not have a source and destination DLCI, but instead a single DLCI field.
3. A. The DLCI in the frame relay header acts as an address, identifying the PVC over which the frame flows.
4. C. The DLCI addresses a VC, not a router. The DLCI value in the frame as it crosses the local link represents that VC on that link. Because the question refers to a frame crossing the access link connected to R1, 222 is the local DLCI on R1 that identifies that VC.

5. A. A single subnet can be used in any Frame Relay topology, but with a full mesh, a single subnet can be used with no tricky issues related to routing protocols.
6. D. BarneyCo has a total of ten VCs. With all of them configured on point-to-point subinterfaces, you need ten subnets because you need one subnet per VC.

Chapter 14

1. C. The correct keywords are **ansi** and **q933**. However, the routers autodetect the LMI type by default, so not configuring the LMI also works.
2. C, D, and E. The LMI type is autosensed by default. Inverse ARP is on by default, as well, meaning that it does not need to be enabled with the **frame-relay inverse-arp** command, nor do any static mapping statements need to be added. Also, no mapping needs to be configured because inverse ARP is enabled by default. Only the **ip address** and **encapsulation** commands need to be configured.
3. A and E. The IP address moves to the subinterface, so it needs to be removed from the serial interface first (with the **no ip address** command). The encapsulation stays on the physical interface. The **frame-relay interface-dlci** command must be used on the subinterface so that the router knows which DLCI goes with which subinterface—even if only one DLCI exists.
4. F. You can code only one DLCI on a **frame-relay interface-dlci** command, and you need one for each VC under the multipoint interface.
5. F. Inverse ARP dynamically advertises information about one router to another router on the other end of a Frame Relay PVC. Specifically, it allows a router to learn a mapping between the PVC and the neighboring router's Layer 3 address.
6. C. Up and down are not PVC status codes. Inactive means that the switch thinks a defined PVC is not working, and deleted means that the DLCI is not defined at the switch. Active means that the router has configured the PVC with that DLCI, and the LMI has confirmed that the PVC is working, so the router will use that PVC.
7. B and D. For a Frame Relay subinterface to be in an up/up state, the underlying physical interface must be in an up/up state, and at least one of the PVCs associated with the subinterface must be in one of the two working PVC states (active or static). The reason answer B can also be true is that if the PVC with DLCI 108 is inactive, the PVCs with DLCI 107 or 109 can be active and the subinterface still be up/up.
8. B and C. For a Frame Relay physical interface to have a line status of up, the same physical layer features as used on leased lines must be working. To also have a protocol status of down, either the router is missing the **encapsulation frame-relay** command or the router and switch disagree about the LMI type.

Chapter 15

1. B. Leased lines offer a Layer 1 service, delivering bits to the other end of the link. Frame Relay and Ethernet WAN services offer Layer 2 services delivering data link frames. MPLS delivers IP packets, discarding incoming data link headers.
2. B and C. As a Layer 3 service, MPLS supports a wide variety of access link types, including Ethernet. Ethernet WAN services, by definition, support Ethernet access links.
3. A and D. Both leased lines and Frame Relay use TDM lines (for example, a T1 line), which then uses a serial interface on a router. VSAT uses a specialized router interface, and Ethernet WANs use a router or switch Ethernet interface.
4. A and C. DSL and cable Internet provide an always-on service. Analog dial and ISDN both require the user to take action, which then dials a phone number at the ISP, establishing a call to the ISP, before data can be transferred.
5. B. ISDN uses symmetric speeds, with 64 Kbps per channel. Cable and DSL use asymmetric speeds, which is generally better for consumer Internet access because more bytes tend to flow from the Internet to the customer, rather than in the opposite (upstream) direction.
6. B and D. The two correct commands must point to each other, by number, to link the physical interface to the dialer interface. The **interface dialer** command does not have to use an interface number that matches. The **ppp chap password 2** command sets the password, and also does not have to match any other value.

Chapter 17

1. B. OSPFv3 uses the exact same rules for choosing its router ID (RID) as does OSPFv2, even choosing the 32-bit RID value based on IPv4 addresses, and not based on the IPv6 addresses. The two answers that mention the **ipv6 address** have no impact on the OSPFv3 RID. For the other incorrect answer, the **ospf router-id** command does not exist; instead, the command is simply the **router-id** command. Only the answer with the **ip address** interface subcommand can impact a router's choice of OSPFv3 RID.
2. B. OSPFv3 does not use a **network** command in OSPFv3 router configuration mode, ruling out two of the answers. It does use an interface subcommand that both refers to the OSPFv3 by process ID and defines the area number. The correct answers lists that interface subcommand with the correct syntax.
3. B. The OSPFv3 configuration would use: **ipv6 router ospf** *process-id,* **router-id** *router-id*, and then under each interface, the **ipv6 ospf** *process-id* **area** *area-id* command. OSPFv2 uses the exact same syntax on the **router-id** command. Only OSPFv3 uses the **ipv6 ospf** *process-id* **area** *area-id* interface subcommand, and OSPFv3 does not use the **network** command.
4. A, D, and E. OSPFv3 uses the same rules as OSPFv2 in regards to all these items except the addresses; OSPFv3 does not require that the neighbors have IPv6 addresses in the same subnet. Mismatched Hello timers prevents neighbor relationships, as do duplicate router IDs. Also, neither can have their interface set to passive; otherwise, the neighbor

relationship fails to complete. The process IDs can be different or the same because they are not checked as part of the choice to become neighbors.

5. B and D. The second line lists the forwarding instructions for the route, specifically the link-local address of the neighboring router and the local router's outgoing interface. These facts identify one correct and one incorrect answer. The OI code indeed means OSPF and interarea; intra-area routes simply omit the *I*. In brackets, the first number is the administrative distance, and the second number (129 in this case) is the metric.
6. C. The correct answer lists detailed information about the OSPFv3 details related to interface G0/1, including a notation that the interface is passive (if it is). Of the incorrect answers, in the **show ipv6 ospf interface passive** command, the **passive** keyword does not exist. The other two commands list all OSPFv3-enabled interfaces on the router, but the list includes passive interfaces, with no notation about which are passive and which are not.

Chapter 18

1. C. IOS supports no direct method for IOS to decide which interfaces have EIGRPv4 enabled, and then automatically enable EIGRPv6 on those same interfaces. The correct answer shows how to enable EIGRPv6 directly on the two interfaces in question. The three incorrect answers also list nonexistent commands.
2. A. The three incorrect answers have separate settings. The Hello timer can be set with the **ip hello-timer eigrp** *asn timer* command for EIGRPv4, and with the IP the **ipv6 hello-timer eigrp** *asn timer* command for EIGRPv6. The **variance** and **maximum-paths** commands, router subcommands, have the same syntax for both routing protocols but are set separately for EIGRPv4 and EIGRPv6. The interface **bandwidth** and **delay** commands impact both EIGRPv4 and EIGRPv6.
3. D. The EIGRPv6 configuration would use **ipv6 router eigrp** *asn*, **eigrp router-id** *router-id*, and then under each interface, the **ipv6 eigrp** *asn* command. EIGRPv6 does not use the **router eigrp** *asn* command (it uses the **ipv6 router eigrp** *asn* command instead), and EIGRPv6 also does not use the **network** command.
4. D. Before the changes, R1 must have had working neighbor relationships with R2, R3, and R4. Once R1's ASN is changed, R1 cannot be neighbors with those same routers, because the ASNs must be the same number to be neighbors. As for the incorrect answers, changing R2's ASN makes R2's neighborships fail, but R1 should use the redundant routes through R3 and R4. The other two answers cause no failures to routes or neighbors at all.
5. B and E. EIGRPv6 uses the same rules as EIGRPv4 in regards to all these items except the addresses; EIGRPv6 does not require that the neighbors have IPv6 addresses in the same subnet. The two routers must use the same ASN, and neither can have its interface set to passive; otherwise, the neighbor relationship fails to complete. However, the Hello timer can be different, the router IDs can be the same, and the IPv6 addresses can be in different subnets.
6. A. The output of this command identifies the neighbor router, based on the neighbor's link-local address on the link between the two routers. The two incorrect answers that mentions the router ID have to be incorrect because EIGRPv6 router IDs are 32-bit values represented as dotted decimal numbers, so they look like IPv4 addresses.

Chapter 19

1. D. The Management Information Base (MIB) resides on a network device. A network management station (NMS) can send commands to the SNMP agent software, which can read/write to the MIB.
2. C. Cisco Prime, formerly known as CiscoWorks, is graphical user interface (GUI) software that can use SNMP and other network management protocols to monitor a Cisco network.
3. B. The Version 2c configuration involves the assignment of a password (called a community string), and the use of a keyword to indicate the level of access permitted with the community string. Possible values are **ro** (meaning read-only, so that SNMP can only monitor the variables) and **rw** (meaning read-write, so that SNMP can change variables to configure the device).
4. C. There are several options for the configuration of SNMP Version 3. You can choose to feature authentication and encryption. Using the noAuthNoPriv method features the use of a username and password only for authentication purposes.
5. D. By default, all message levels are logged to the console on a Cisco device. To do so, IOS uses logging level 7 (debugging), which causes IOS to send severity level 7, and levels below 7, to the console. All the incorrect answers list levels below level 7.
6. C. The **logging trap 4** command limits those messages sent to a syslog server (configured with the **logging** *ip-address* command) to levels 4 and below, thus 0 through 4.
7. D. The input logical interface can be used to help identify a flow, but not the output logical interface. It also uses various fields in the headers used in packets sent within a flow, notably the port numbers, IP addresses, ToS field values, and Layer 3 protocol type.
8. C. The interface-level command to ensure NetFlow captures egress traffic statistics is **ip flow egress**.

Chapter 20

1. B. The Power-On Self-Test is the first phase of the boot process on a Cisco router. This ensures there is an inventory of functional hardware components in place on the device.
2. B. The first step in the process of locating a Cisco IOS image is to check the boot field of the configuration register. This value instructs the router whether to load ROMMON or IOS, and if IOS, specifically the steps to take to find the IOS to load. This first step (the boot field) usually instructs the router to use the image file in flash.
3. D. The **show version** command is a simple way to verify the location and image file name of the operating system that your Cisco router is running. Of the other answers, only **show running-config** is a valid command.
4. D. The last hexadecimal character in the configuration register is called the boot field. It controls how the router boots.

For example, this character can be set on the router to force the device to boot into ROMMON mode.

5. A. As part of the password recovery process, you must reset the configuration register to have the router ignore the existing startup configuration. This can be accomplished by entering ROMMON mode.
6. A. IOS uses RAM to store working items, like the running-config file and working memory for IOS. It uses ROM for permanent storage of the POST and bootstrap code, flash for the IOS and other files, and NVRAM for the startup-config file.
7. B. When a Cisco router boots and does not find a valid configuration file in NVRAM, the router asks users if they want to use the "initial configuration dialogue," also known as setup. This mode prompts the administrator for various configuration elements such as hostname and interface IP addresses.

Chapter 21

1. D. The traditional Cisco IOS image model created a different IOS file for each combination of features, even for a single version and single model. In this case, model *X*, for a single version, would have one IOS image for the Base software, another for Base + Data, another for Base + Voice, another for Base + Security, and even other images for other combinations, like Base + all the extra feature sets.
2. A. The new Cisco IOS image file that provides access to all major features is called the universal image.
3. C. To take advantage of advanced security features, use the securityk9 license.
4. B. The UDI has two main components: the product ID (PID) and the serial number (SN).
5. D. To enable a purchased license, the customer receives a PAK. At some point in the process, the customer downloads the license key file, and then puts that file somewhere from which the router can copy the file using the **license install** *url* exec command.
6. A. To enable a right-to-use license, the customer does not need to receive a PAK. Instead, the customer references the specific license by name with the **license boot** command. Of the two answers that use this command, only one of them happens to use the correct syntax. Once the configured is added and saved, the router starts using the license after the next reload.

Appendix D. Memory Tables

Chapter 1

Table 1-2. Three Classes of Problems Caused by Not Using STP in Redundant LANs

Problem	Description
Broadcast storms	
MAC table instability	
Multiple frame transmission	

Table 1-3. STP: Reasons for Forwarding or Blocking

Characterization of Port	STP State	Description
All the root switch's ports		
Each nonroot switch's root port		
Each LAN's designated port		
All other working ports		

Table 1-4. Fields in the STP Hello BPDU

Field	Description
Root bridge ID	
Sender's bridge ID	
Sender's root cost	
Timer values on the root switch	

Table 1-6. Default Port Costs According to IEEE

Ethernet Speed	IEEE Cost
10 Mbps	
100 Mbps	
1 Gbps	
10 Gbps	

Chapter 3

Table 3-2. LAN Switch Interface Status Codes

Line Status	Protocol Status	Interface Status	Typical Root Cause
admin. down	down		
down	down		
up	down		
down	down (err-disabled)		
up	up		

Table 3-3. 10BASE-T and 100BASE-T Pin Pairs Used

Devices That Transmit on 1,2 and Receive on 3,6	Devices That Transmit on 3,6 and Receive on 1,2

Table 3-4. Actions When Port Security Violation Occurs, Based on Mode

Option on the switchport port-security violation Command	Protect	Restrict	Shut Down*
Discards offending traffic			
Disables the interface, discarding all traffic			
Increments violation counter for each violating frame			

*Shut down is the default setting.

Table 3-7. Expected Trunking Operational Mode Based on the Configured Administrative Modes

Administrative Mode	Access	Dynamic Auto	Trunk	Dynamic Desirable
access				
dynamic auto				
trunk				
dynamic desirable				

Chapter 5

Table 5-1. Common Reasons Why Router LAN Interfaces Are Not Up/Up

Reason	Description	Router Interface State
Speed mismatch		
Shutdown		
Err-disabled switch		
No cable/bad cable		

* Cisco switches use a feature called auto-mdix, which automatically detects some incorrect cabling pinouts and internally changes the pin logic to allow the cable to be used. As a result, not all incorrect cable pinouts result in an interface failing.

Chapter 6

Table 6-2. Three FHRP Options

Acronym	Full Name	Origin	Redundancy Approach	Load Balancing
HSRP	Hot Standby Router Protocol			
VRRP	Virtual Router Redundancy Protocol			
GLBP	Gateway Load Balancing Protocol			

Chapter 7

Table 7-2. Types of VPNs

Type	Typical Purpose
	A site-to-site VPN that connects all the computers at two sites of the same organization, usually using one VPN device at each site
	A site-to-site VPN that connects all the computers at two sites of different but partnering organizations, usually using one VPN device at each site
	Connects individual Internet users to the enterprise network

Chapter 8

Table 8-3. OSPF Design Terminology

Term	Description
Area Border Router (ABR)	
Backbone router	
Internal router	
Area	
Backbone area	
Intra-area route	
Interarea route	

Table 8-4. The Three OSPFv2 LSA Types Seen with a Multi-Area OSPF Design

Name	Number	Primary Purpose	Contents of LSA
Router LSA			
Network			
Summary			

Table 8-6. Default Administrative Distances

Route Type	Administrative Distance
Connected	
Static	
BGP (external routes)	20
EIGRP (internal routes)	
IGRP	100
OSPF	
IS-IS	
RIP	
EIGRP (external routes)	170
BGP (internal routes)	200
Unusable	255

Table 8-7. OSPF Cost Calculation Examples with Default Bandwidth Settings

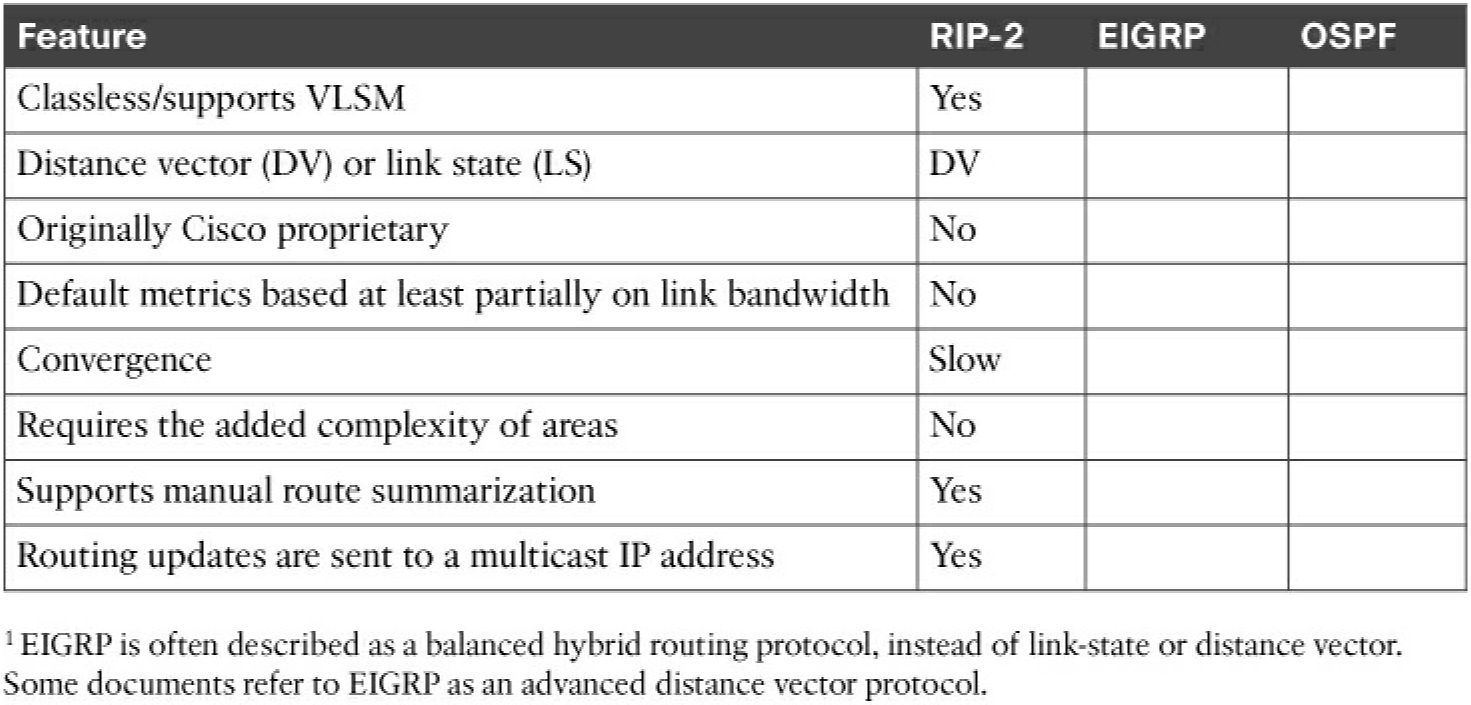
Interface	Interface Default Bandwidth (Kbps)	Formula (Kbps)	OSPF Cost
Serial			
Ethernet			
Fast Ethernet			

Table 8-8. Faster Interfaces with Equal OSPF Costs

Interface	Interface Default Bandwidth (Kbps)	Formula (Kbps)	OSPF Cost
Fast Ethernet			
Gigabit Ethernet			
10 Gigabit Ethernet			
100 Gigabit Ethernet			

Chapter 9

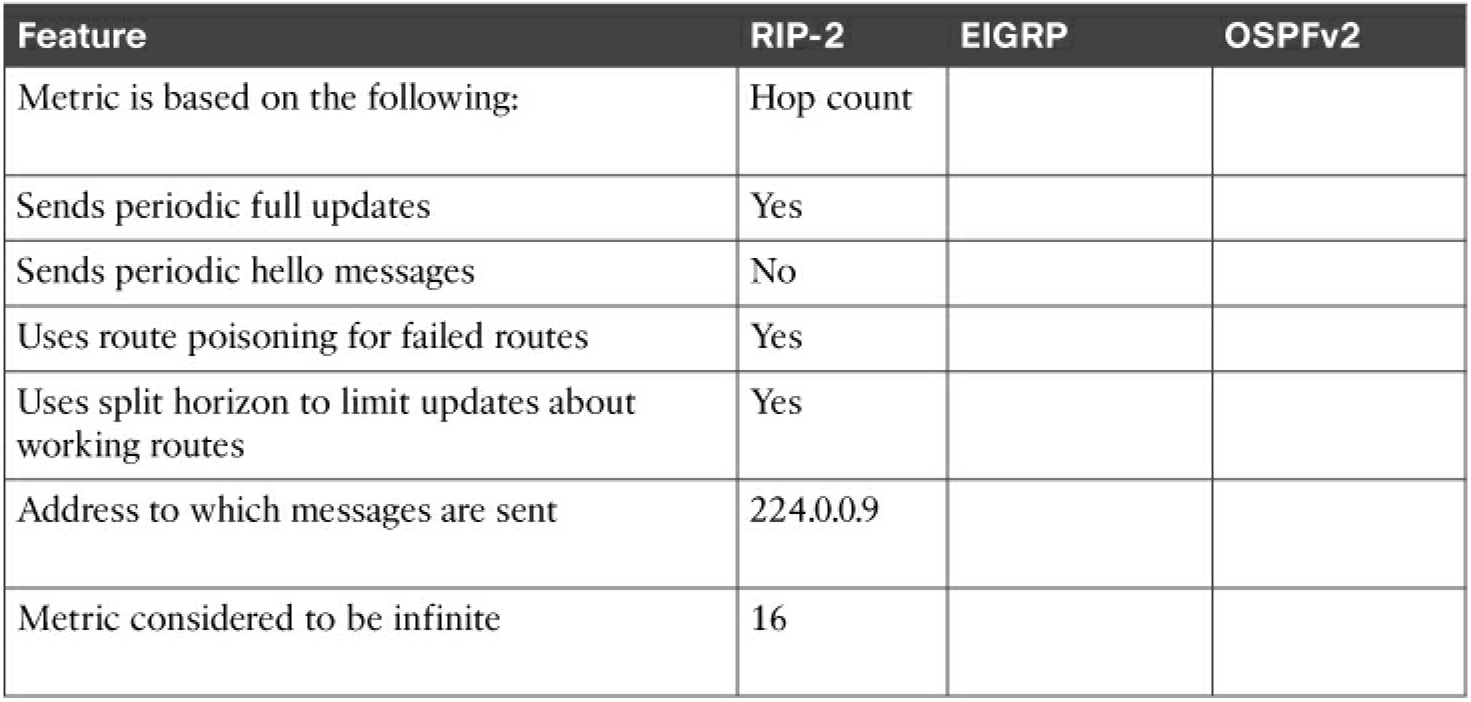
Table 9-2. Interior IP Routing Protocols Compared



Feature	RIP-2	EIGRP	OSPF
Classless/supports VLSM	Yes		
Distance vector (DV) or link state (LS)	DV		
Originally Cisco proprietary	No		
Default metrics based at least partially on link bandwidth	No		
Convergence	Slow		
Requires the added complexity of areas	No		
Supports manual route summarization	Yes		
Routing updates are sent to a multicast IP address	Yes		

[1] EIGRP is often described as a balanced hybrid routing protocol, instead of link-state or distance vector. Some documents refer to EIGRP as an advanced distance vector protocol.

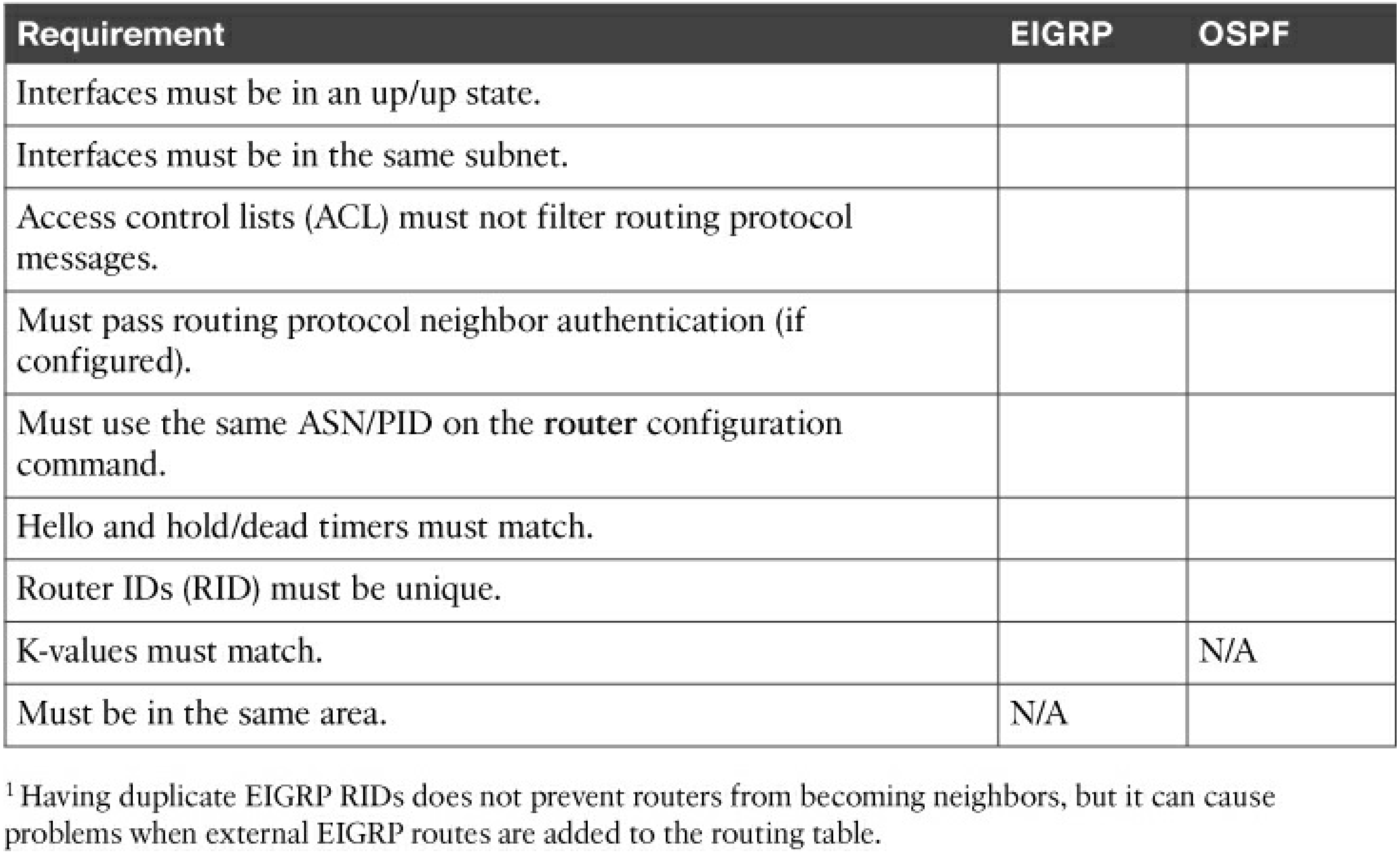
Table 9-3. Interior IP Routing Protocols Compared



Feature	RIP-2	EIGRP	OSPFv2
Metric is based on the following:	Hop count		
Sends periodic full updates	Yes		
Sends periodic hello messages	No		
Uses route poisoning for failed routes	Yes		
Uses split horizon to limit updates about working routes	Yes		
Address to which messages are sent	224.0.0.9		
Metric considered to be infinite	16		

Chapter 11

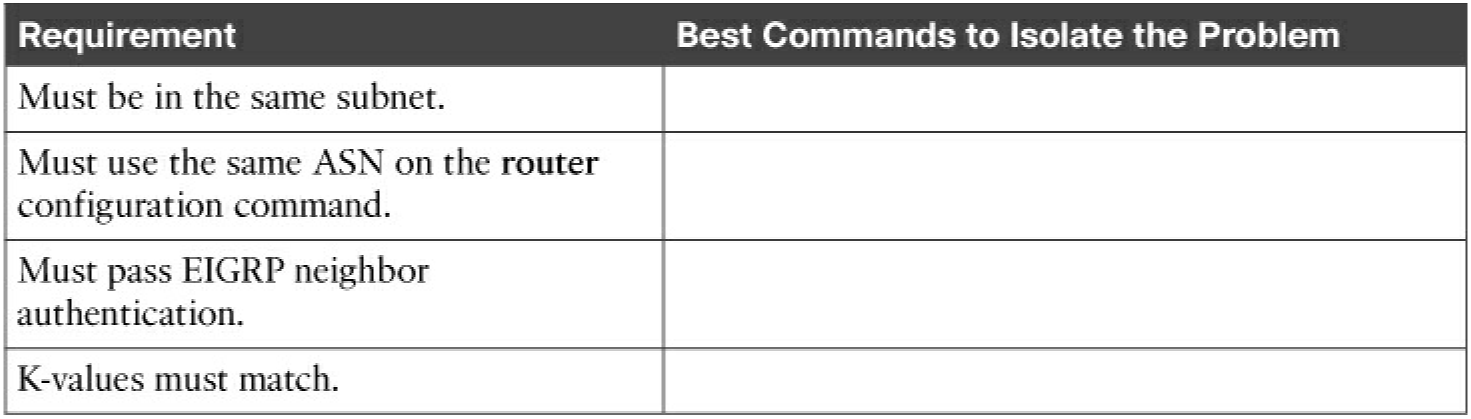
Table 11-2. Neighbor Requirements for EIGRP and OSPF



Requirement	EIGRP	OSPF
Interfaces must be in an up/up state.		
Interfaces must be in the same subnet.		
Access control lists (ACL) must not filter routing protocol messages.		
Must pass routing protocol neighbor authentication (if configured).		
Must use the same ASN/PID on the **router** configuration command.		
Hello and hold/dead timers must match.		
Router IDs (RID) must be unique.		
K-values must match.		N/A
Must be in the same area.	N/A	

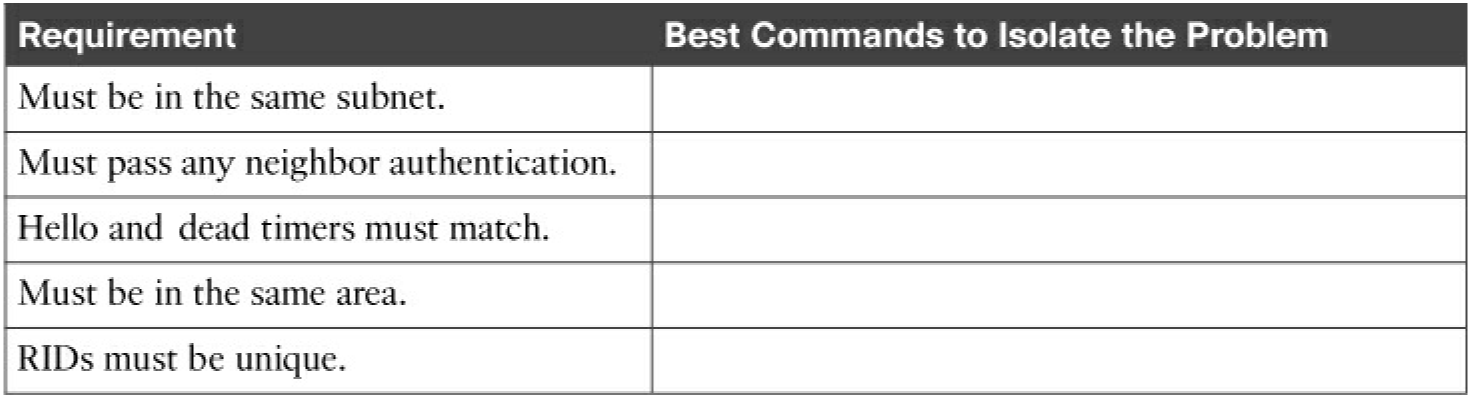
[1] Having duplicate EIGRP RIDs does not prevent routers from becoming neighbors, but it can cause problems when external EIGRP routes are added to the routing table.

Table 11-3. EIGRP Neighbor Requirements and the Best show/debug **Commands**



Requirement	Best Commands to Isolate the Problem
Must be in the same subnet.	
Must use the same ASN on the **router** configuration command.	
Must pass EIGRP neighbor authentication.	
K-values must match.	

Table 11-4. OSPF Neighbor Requirements and the Best show/debug **Commands**



Requirement	Best Commands to Isolate the Problem
Must be in the same subnet.	
Must pass any neighbor authentication.	
Hello and dead timers must match.	
Must be in the same area.	
RIDs must be unique.	

Chapter 12

Table 12-5. Interface Status Codes and Typical Meanings When a Ping Does Not Work

Line Status	Protocol Status	Likely General Reason/Layer
Administratively down	Down	
Down	Down	
Up	Down	
Up	Up	

Table 12-6. Likely Reasons for Data Link Problems on Serial Links

Line Status	Protocol Status	Likely Reason
Up	Down on both ends[1]	
Up	Down on one end, up on the other	
Up	Down on both ends	

[1] In this case, the state may flap from up/up, to up/down, to up/up, and so on, while the router keeps trying to make the encapsulation work.

Table 12-7. Summary of Symptoms for Mismatched Subnets on Serial Links

Symptoms When IP Addresses on a Serial Link Are in Different Subnets	HDLC	PPP
Does a ping of the other router's serial IP address work?		
Can routing protocols exchange routes over the link?		

Chapter 13

Table 13-3. Frame Relay LMI Types

Name	Document	IOS LMI-Type Parameter
Cisco	Proprietary	
ANSI	T1.617 Annex D	
ITU	Q.933 Annex A	

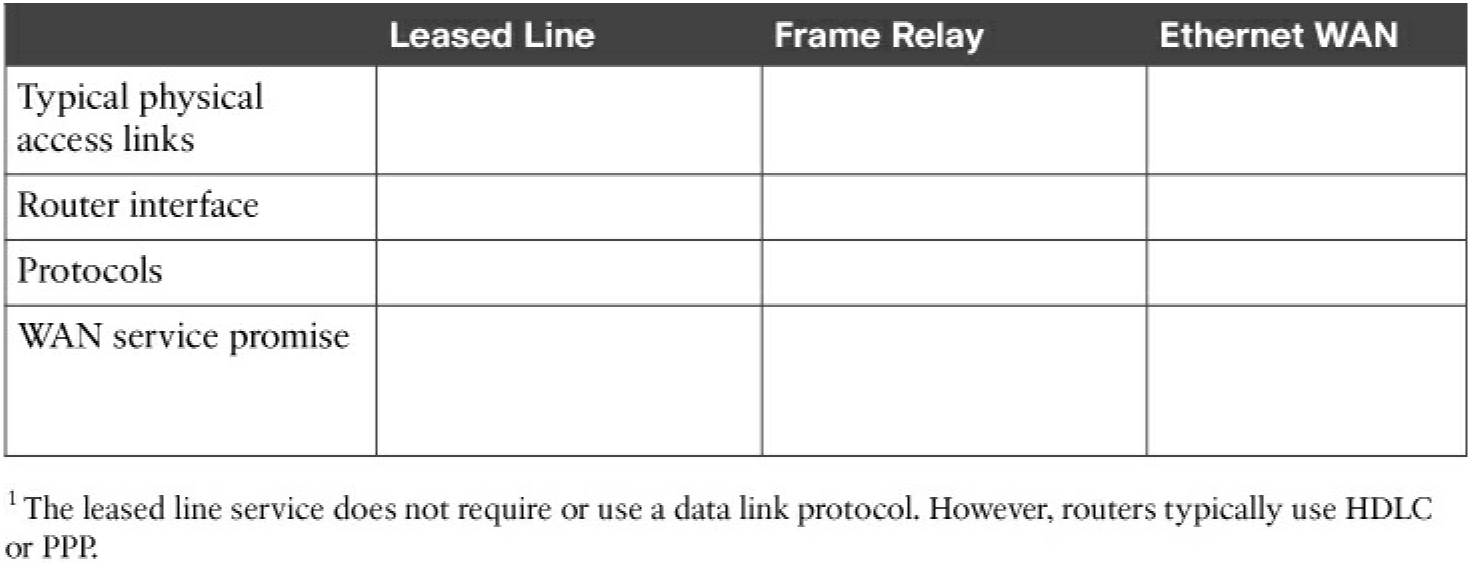
Chapter 14

Table 14-3. PVC Status Values

Status	Active	Inactive	Deleted	Static
The PVC is defined to the Frame Relay network.				
The router will attempt to send frames on a VC in this state.				

Chapter 15

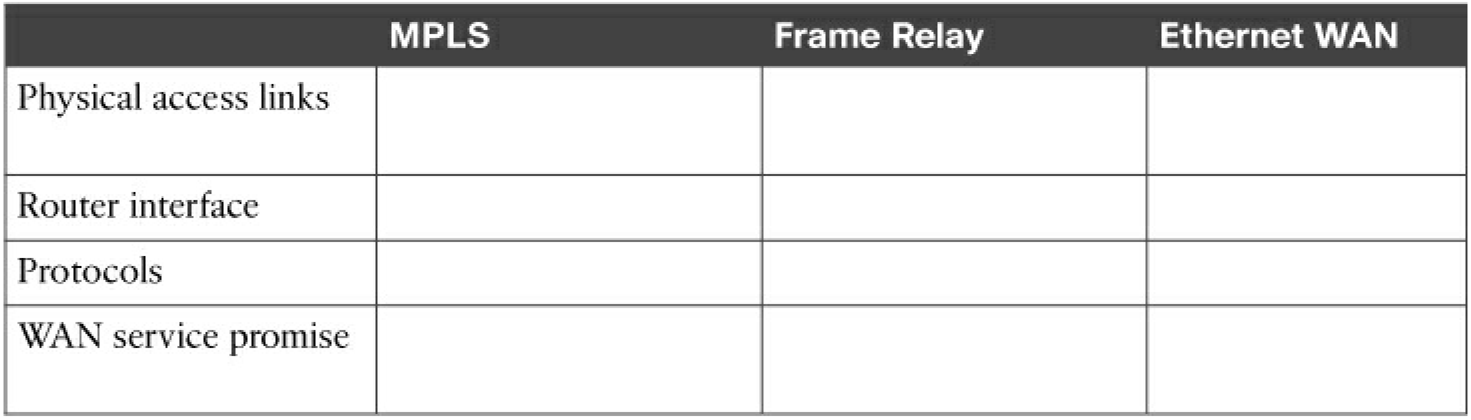
Table 15-3. Key Comparison Points for Ethernet WAN, Frame Relay, and Leased Lines



	Leased Line	Frame Relay	Ethernet WAN
Typical physical access links			
Router interface			
Protocols			
WAN service promise			

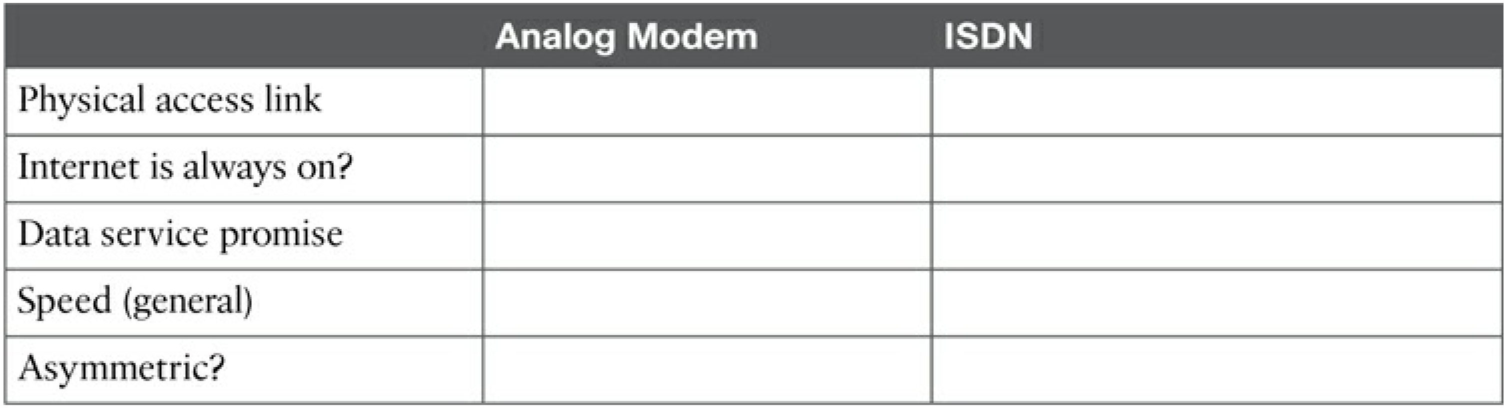
[1] The leased line service does not require or use a data link protocol. However, routers typically use HDLC or PPP.

Table 15-4. Key Comparison Points for Ethernet WAN, Frame Relay, and MPLS



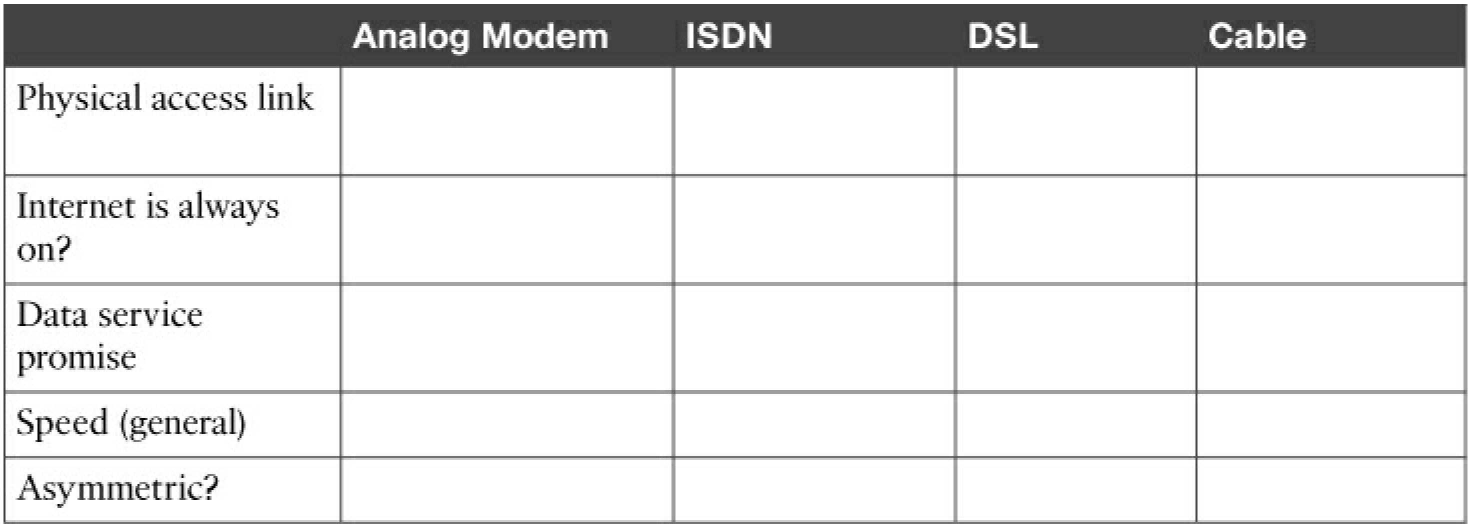
	MPLS	Frame Relay	Ethernet WAN
Physical access links			
Router interface			
Protocols			
WAN service promise			

Table 15-5. Comparison of Internet Access Technologies



	Analog Modem	ISDN
Physical access link		
Internet is always on?		
Data service promise		
Speed (general)		
Asymmetric?		

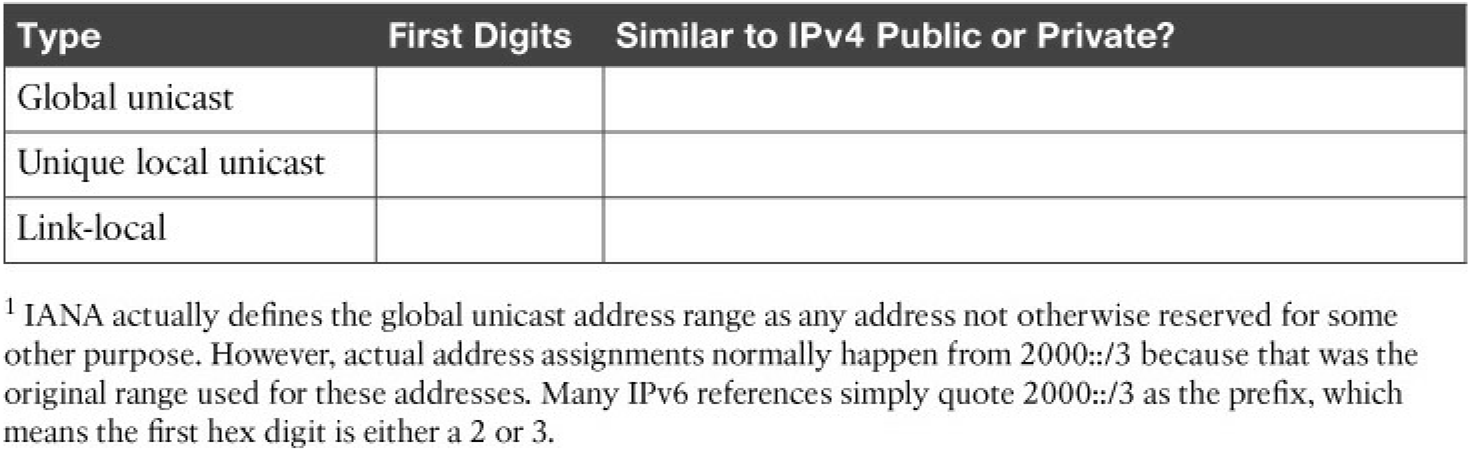
Table 15-6. Comparison of Internet Access Technologies



	Analog Modem	ISDN	DSL	Cable
Physical access link				
Internet is always on?				
Data service promise				
Speed (general)				
Asymmetric?				

Chapter 16

Table 16-1. Summary of IPv6 Unicast Address Types

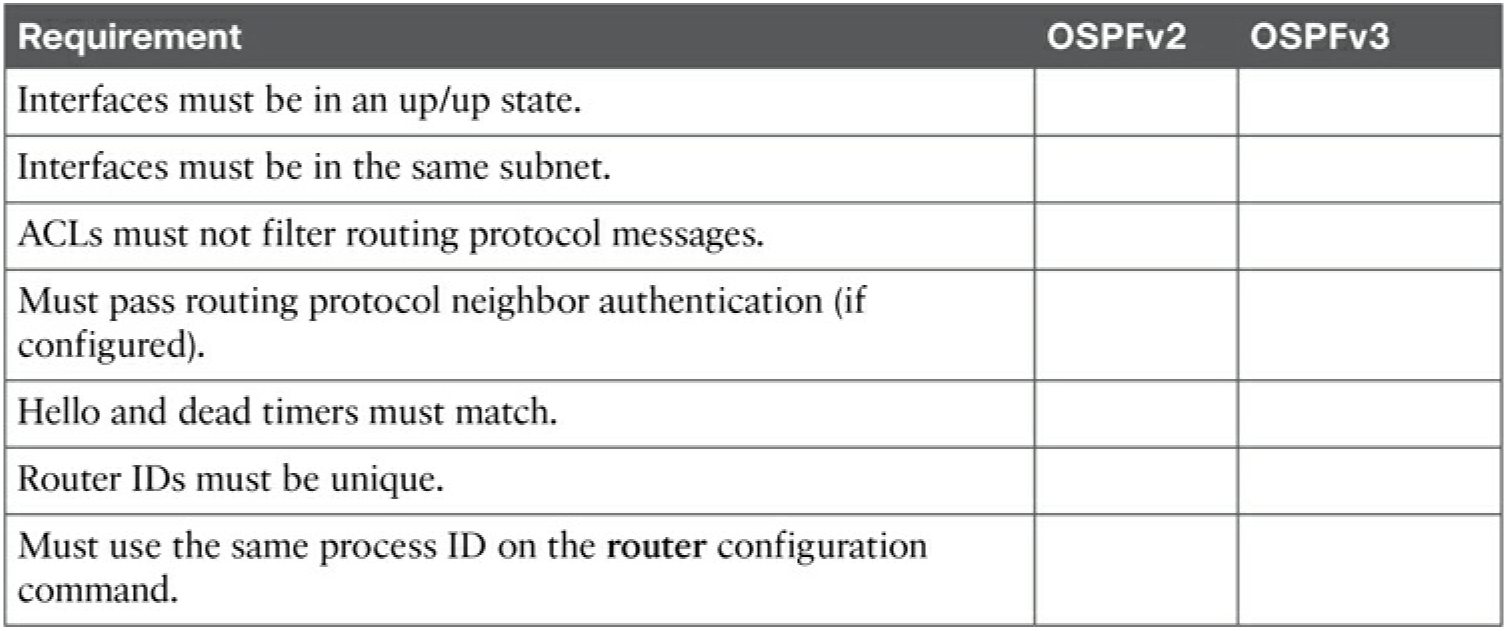


Type	First Digits	Similar to IPv4 Public or Private?
Global unicast		
Unique local unicast		
Link-local		

[1] IANA actually defines the global unicast address range as any address not otherwise reserved for some other purpose. However, actual address assignments normally happen from 2000::/3 because that was the original range used for these addresses. Many IPv6 references simply quote 2000::/3 as the prefix, which means the first hex digit is either a 2 or 3.

Chapter 17

Table 17-2. Neighbor Requirements for OSPFv2 and OSPFv3



Requirement	OSPFv2	OSPFv3
Interfaces must be in an up/up state.		
Interfaces must be in the same subnet.		
ACLs must not filter routing protocol messages.		
Must pass routing protocol neighbor authentication (if configured).		
Hello and dead timers must match.		
Router IDs must be unique.		
Must use the same process ID on the **router** configuration command.		

Table 17-3. OSPF Neighbor Requirements and the Best show/debug **Commands**

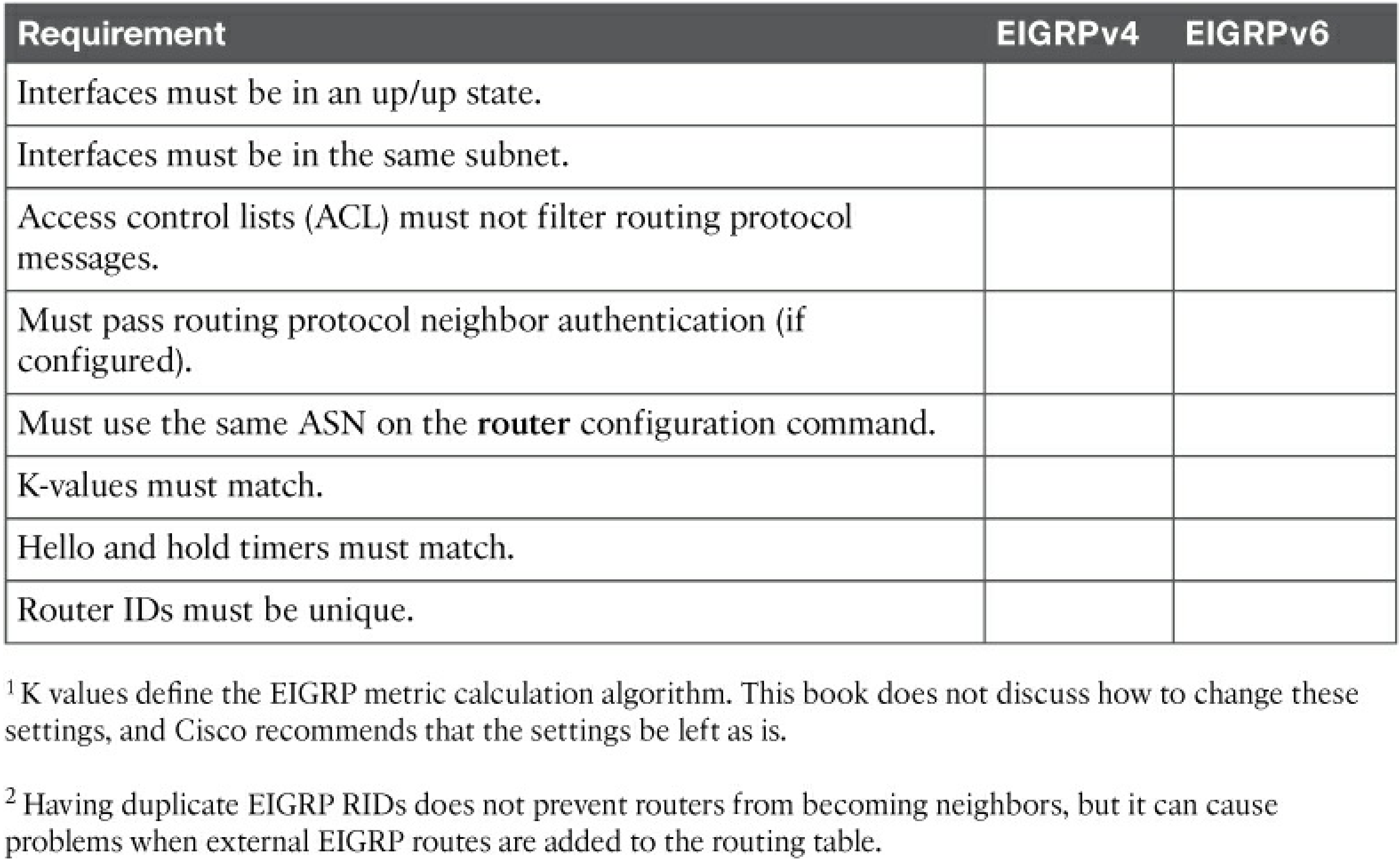
Requirement	Best Commands to Isolate the Problem
Must pass any neighbor authentication.	
Hello and dead timers must match.	
Must be in the same area.	
Router IDs must be unique.	
Interfaces must not be passive.	

Chapter 18

Table 18-2. Comparison of EIGRPv4 and EIGRPv6 Configuration Commands

Function	EIGRPv4	EIGRPv6
Create process, define ASN		
Define router ID explicitly (router mode)		
Change number of concurrent routes (router mode)		
Set the variance multiplier (router mode)		
Influence metric calculation (interface mode)		
Change hello and hold timers (interface mode)		
Enable EIGRP on an interface		
Disable and enable automatic summarization (router mode)		

Table 18-3. Neighbor Requirements for EIGRPv4 and EIGRPv6



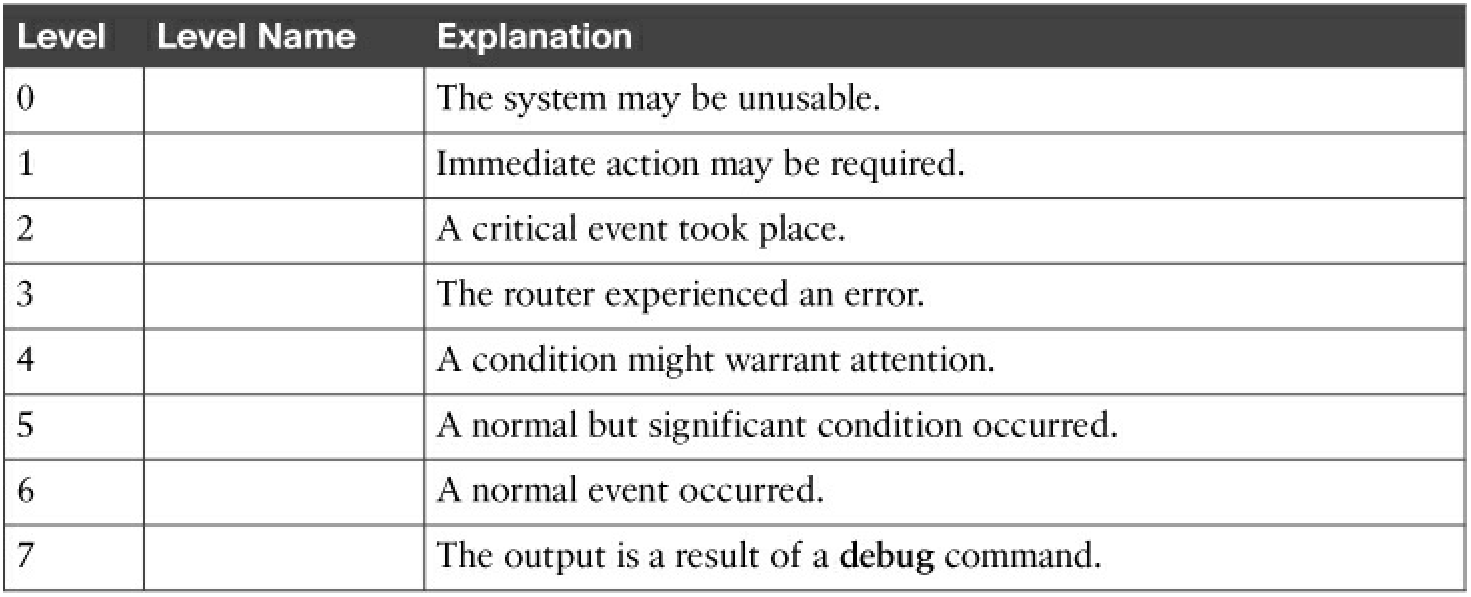
Requirement	EIGRPv4	EIGRPv6
Interfaces must be in an up/up state.		
Interfaces must be in the same subnet.		
Access control lists (ACL) must not filter routing protocol messages.		
Must pass routing protocol neighbor authentication (if configured).		
Must use the same ASN on the **router** configuration command.		
K-values must match.		
Hello and hold timers must match.		
Router IDs must be unique.		

[1] K values define the EIGRP metric calculation algorithm. This book does not discuss how to change these settings, and Cisco recommends that the settings be left as is.

[2] Having duplicate EIGRP RIDs does not prevent routers from becoming neighbors, but it can cause problems when external EIGRP routes are added to the routing table.

Chapter 19

Table 19-3. System Message Severity Levels

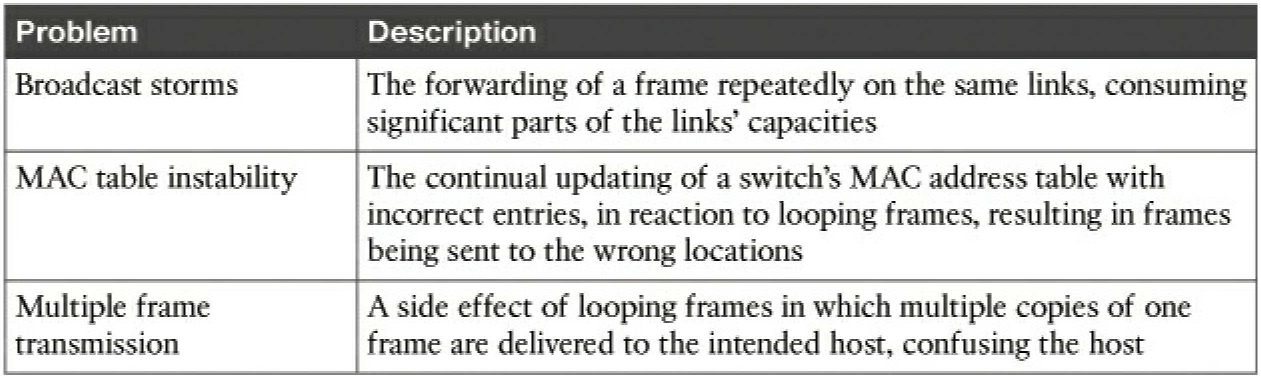


Level	Level Name	Explanation
0		The system may be unusable.
1		Immediate action may be required.
2		A critical event took place.
3		The router experienced an error.
4		A condition might warrant attention.
5		A normal but significant condition occurred.
6		A normal event occurred.
7		The output is a result of a **debug** command.

Appendix E. Memory Tables Answer Key

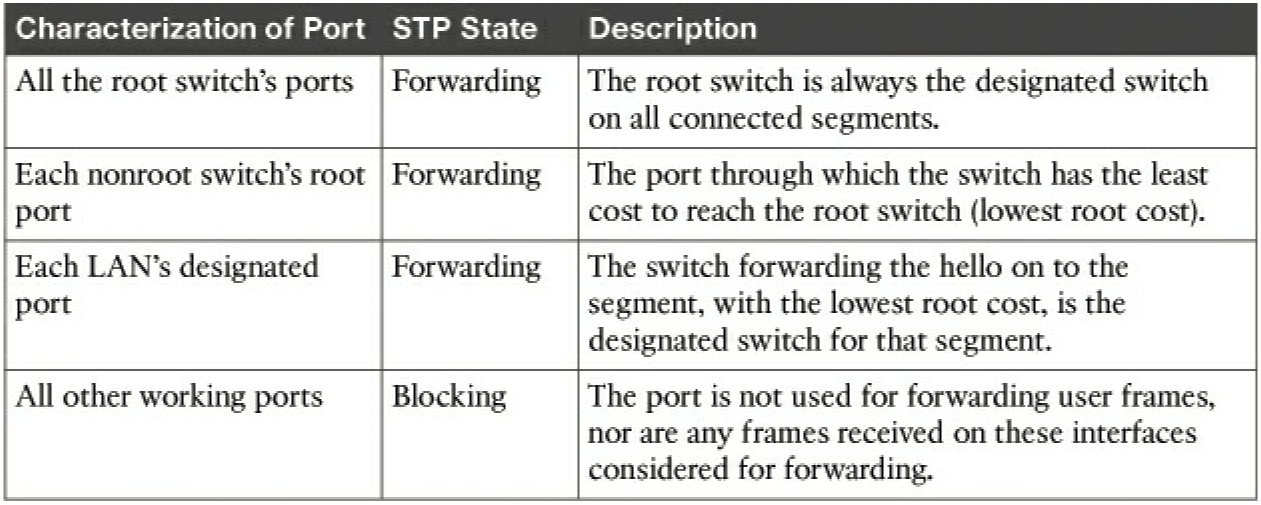
Chapter 1

Table 1-2. Three Classes of Problems Caused by Not Using STP in Redundant LANs



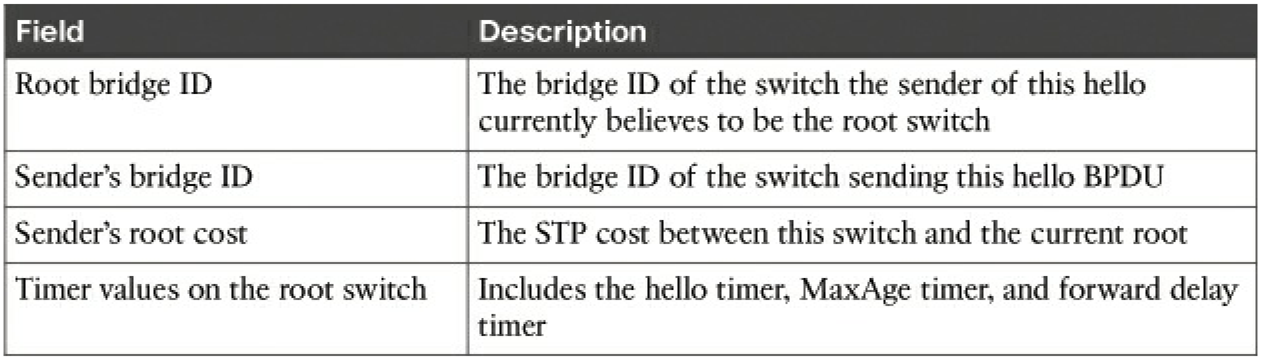
Problem	Description
Broadcast storms	The forwarding of a frame repeatedly on the same links, consuming significant parts of the links' capacities
MAC table instability	The continual updating of a switch's MAC address table with incorrect entries, in reaction to looping frames, resulting in frames being sent to the wrong locations
Multiple frame transmission	A side effect of looping frames in which multiple copies of one frame are delivered to the intended host, confusing the host

Table 1-3. STP: Reasons for Forwarding or Blocking



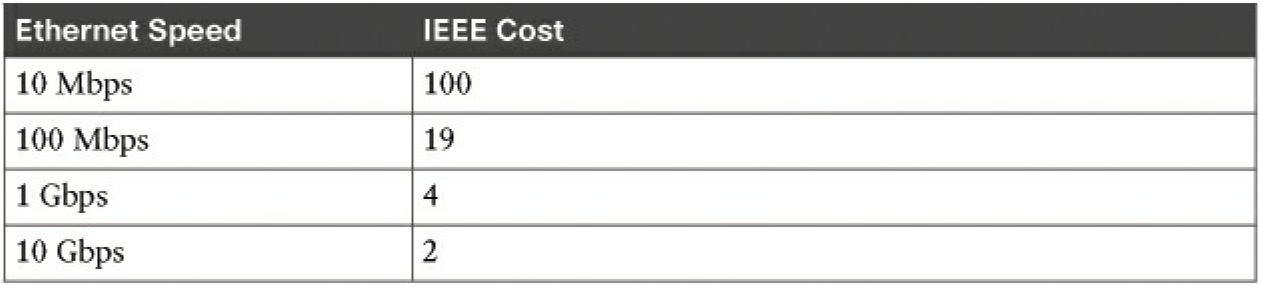
Characterization of Port	STP State	Description
All the root switch's ports	Forwarding	The root switch is always the designated switch on all connected segments.
Each nonroot switch's root port	Forwarding	The port through which the switch has the least cost to reach the root switch (lowest root cost).
Each LAN's designated port	Forwarding	The switch forwarding the hello on to the segment, with the lowest root cost, is the designated switch for that segment.
All other working ports	Blocking	The port is not used for forwarding user frames, nor are any frames received on these interfaces considered for forwarding.

Table 1-4. Fields in the STP Hello BPDU



Field	Description
Root bridge ID	The bridge ID of the switch the sender of this hello currently believes to be the root switch
Sender's bridge ID	The bridge ID of the switch sending this hello BPDU
Sender's root cost	The STP cost between this switch and the current root
Timer values on the root switch	Includes the hello timer, MaxAge timer, and forward delay timer

Table 1-6. Default Port Costs According to IEEE



Ethernet Speed	IEEE Cost
10 Mbps	100
100 Mbps	19
1 Gbps	4
10 Gbps	2

Chapter 3

Table 3-2. LAN Switch Interface Status Codes

Line Status	Protocol Status	Interface Status	Typical Root Cause
admin. down	down	disabled	Interface is configured with the **shutdown** command.
down	down	notconnect	No cable, bad cable, wrong cable pinouts, speeds mismatched on the two connected devices, or device on the other end of the cable is either powered off or the other interface is shut down.
up	down	notconnect	Not expected on LAN switch interfaces.
down	down (err-disabled)	err-disabled	Port security has disabled the interface. EtherChannel uses this state for interfaces in the channel whose configuration does not match other interfaces in the channel.
up	up	connected	Interface is working.

Table 3-3. 10BASE-T and 100BASE-T Pin Pairs Used

Devices That Transmit on 1,2 and Receive on 3,6	Devices That Transmit on 3,6 and Receive on 1,2
PC NICs	Hubs
Routers	Switches
Wireless access points (Ethernet interface)	—
Ethernet-connected network printers	—

Table 3-4. Actions When Port Security Violation Occurs, Based on Mode

Option on the switchport port-security violation Command	Protect	Restrict	Shut Down*
Discards offending traffic	Yes	Yes	Yes
Disables the interface, discarding all traffic	No	No	Yes
Increments violation counter for each violating frame	No	Yes	Yes

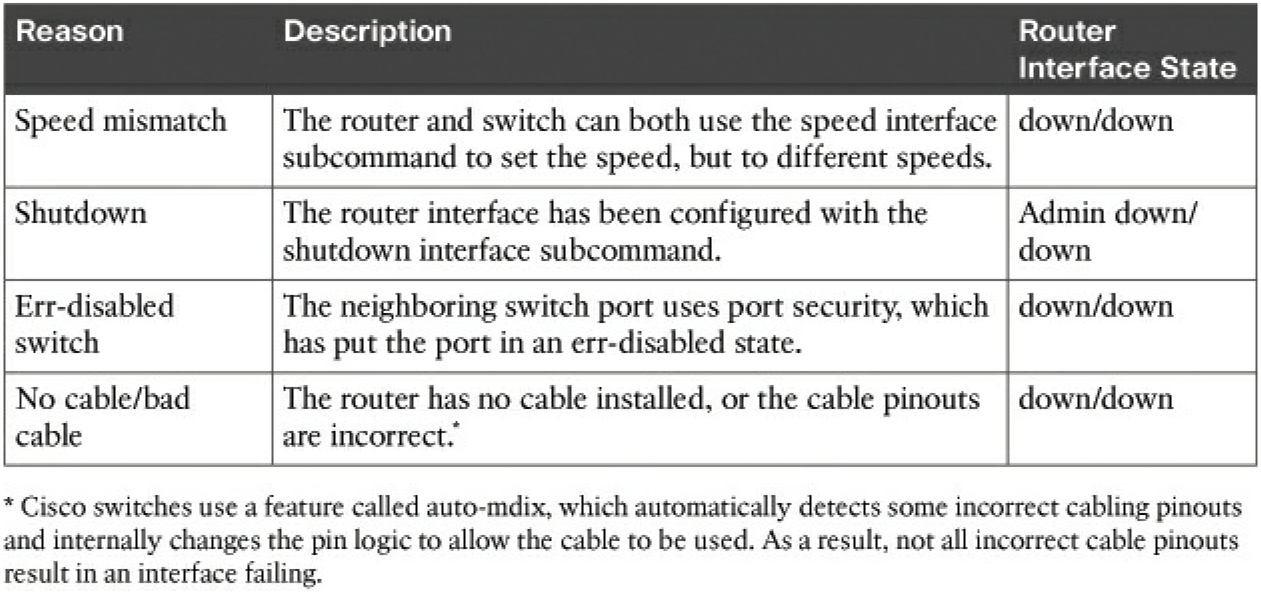
* Shut down is the default setting.

Table 3-7. Expected Trunking Operational Mode Based on the Configured Administrative Modes

Administrative Mode	Access	Dynamic Auto	Trunk	Dynamic Desirable
access	Access	Access	Access	Access
dynamic auto	Access	Access	Trunk	Trunk
trunk	Access	Trunk	Trunk	Trunk
dynamic desirable	Access	Trunk	Trunk	Trunk

Chapter 5

Table 5-1. Common Reasons Why Router LAN Interfaces Are Not Up/Up

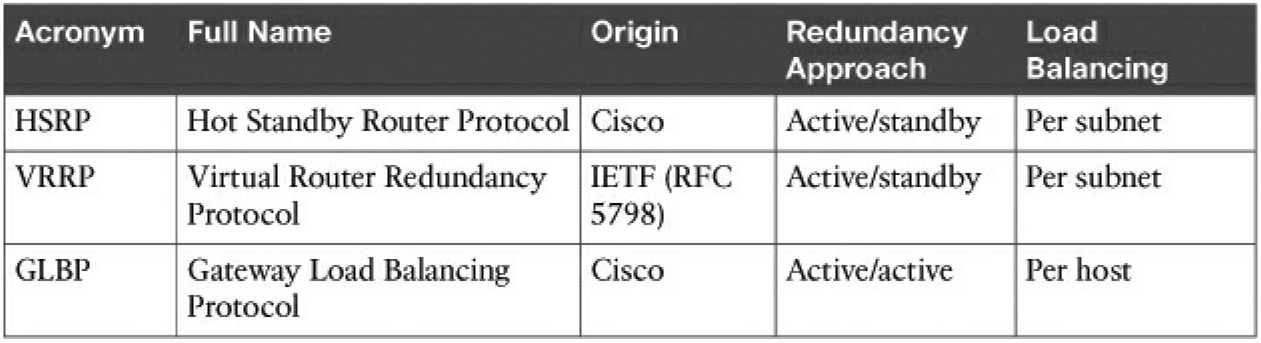


Reason	Description	Router Interface State
Speed mismatch	The router and switch can both use the speed interface subcommand to set the speed, but to different speeds.	down/down
Shutdown	The router interface has been configured with the shutdown interface subcommand.	Admin down/ down
Err-disabled switch	The neighboring switch port uses port security, which has put the port in an err-disabled state.	down/down
No cable/bad cable	The router has no cable installed, or the cable pinouts are incorrect.*	down/down

* Cisco switches use a feature called auto-mdix, which automatically detects some incorrect cabling pinouts and internally changes the pin logic to allow the cable to be used. As a result, not all incorrect cable pinouts result in an interface failing.

Chapter 6

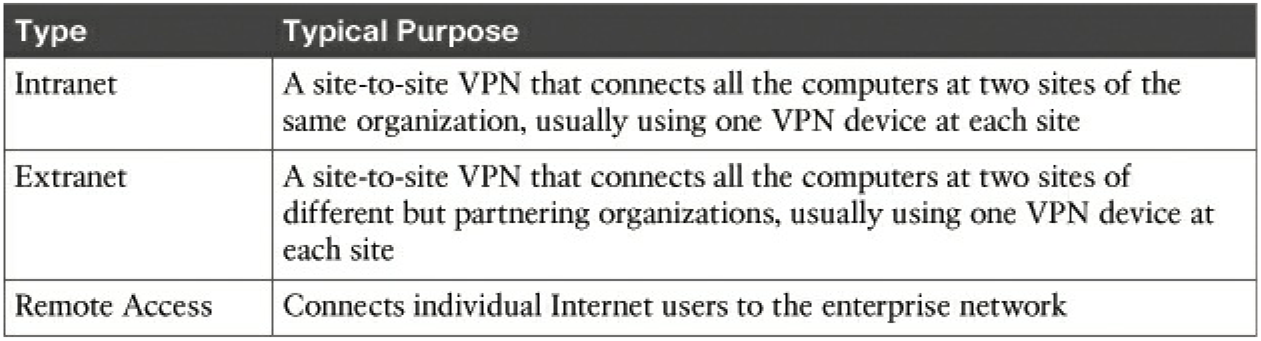
Table 6-2. Three FHRP Options



Acronym	Full Name	Origin	Redundancy Approach	Load Balancing
HSRP	Hot Standby Router Protocol	Cisco	Active/standby	Per subnet
VRRP	Virtual Router Redundancy Protocol	IETF (RFC 5798)	Active/standby	Per subnet
GLBP	Gateway Load Balancing Protocol	Cisco	Active/active	Per host

Chapter 7

Table 7-2. Types of VPNs



Type	Typical Purpose
Intranet	A site-to-site VPN that connects all the computers at two sites of the same organization, usually using one VPN device at each site
Extranet	A site-to-site VPN that connects all the computers at two sites of different but partnering organizations, usually using one VPN device at each site
Remote Access	Connects individual Internet users to the enterprise network

Chapter 8

Table 8-3. OSPF Design Terminology

Term	Description
Area Border Router (ABR)	An OSPF router with interfaces connected to the backbone area and to at least one other area
Backbone router	A router in one area (the backbone area)
Internal router	A router in one area (not the backbone area)
Area	A set of routers and links that share the same detailed LSDB information, but not with routers in other areas, for better efficiency
Backbone area	A special OSPF area to which all other areas must connect—area 0
Intra-area route	A route to a subnet inside the same area as the router
Interarea route	A route to a subnet in an area of which the router is not a part

Table 8-4. The Three OSPFv2 LSA Types Seen with a Multi-Area OSPF Design

Name	Number	Primary Purpose	Contents of LSA
Router LSA	1	Describe Router	RID, interfaces, IP address/mask, current interface state (status)
Network	2	Describe network that has a DR	DR and BDR IP addresses, subnet ID, mask
Summary	3	Describe a subnet in another area	Subnet ID, mask, RID of ABR that advertises the LSA

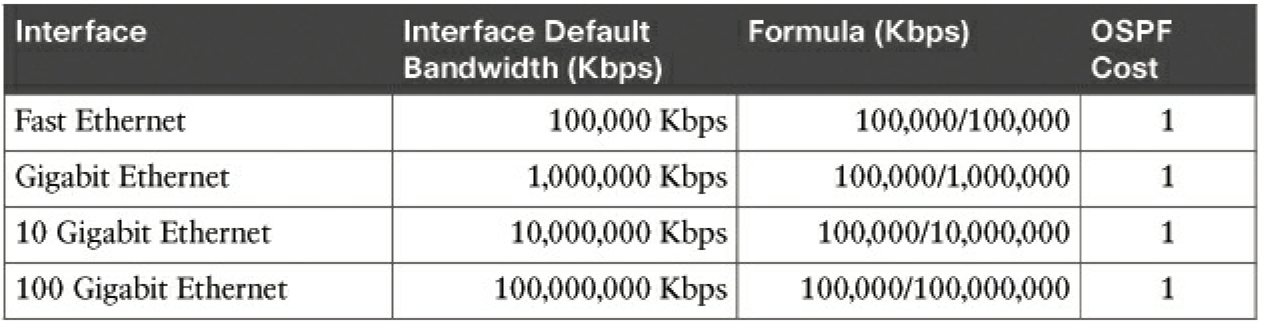
Table 8-6. Default Administrative Distances

Route Type	Administrative Distance
Connected	0
Static	1
BGP (external routes)	20
EIGRP (internal routes)	90
IGRP	100
OSPF	110
IS-IS	115
RIP	120
EIGRP (external routes)	170
BGP (internal routes)	200
Unusable	255

Table 8-7. OSPF Cost Calculation Examples with Default Bandwidth Settings

Interface	Interface Default Bandwidth (Kbps)	Formula (Kbps)	OSPF Cost
Serial	1544 Kbps	100,000/1544	64
Ethernet	10,000 Kbps	100,000/10,000	10
Fast Ethernet	100,000 Kbps	100,000/100,000	1

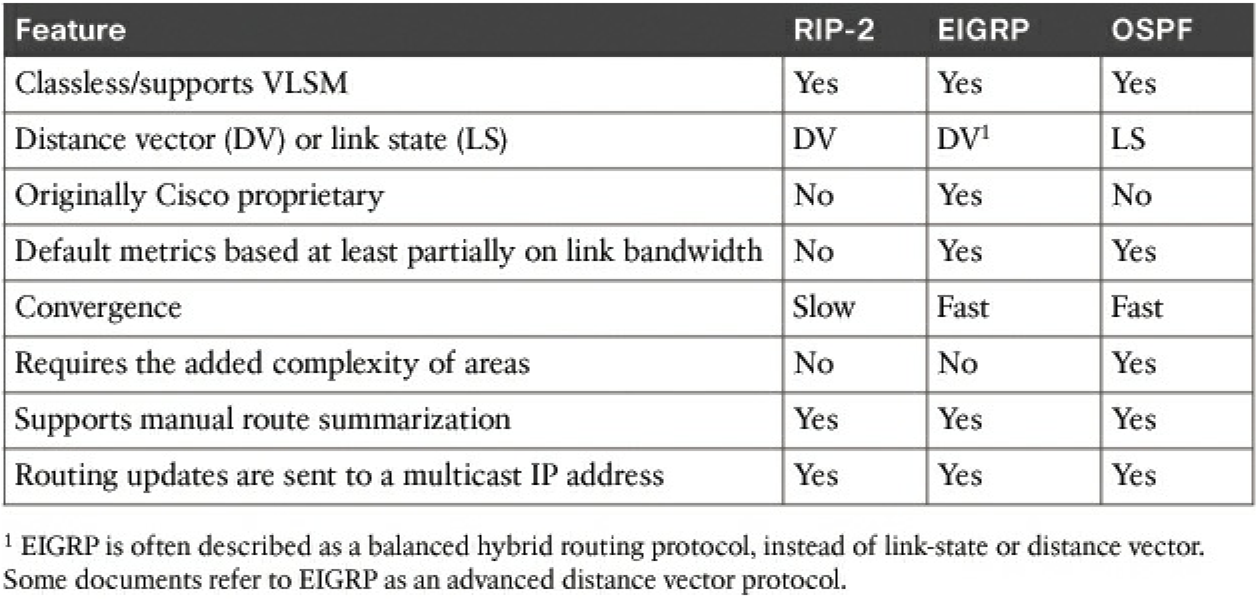
Table 8-8. Faster Interfaces with Equal OSPF Costs



Interface	Interface Default Bandwidth (Kbps)	Formula (Kbps)	OSPF Cost
Fast Ethernet	100,000 Kbps	100,000/100,000	1
Gigabit Ethernet	1,000,000 Kbps	100,000/1,000,000	1
10 Gigabit Ethernet	10,000,000 Kbps	100,000/10,000,000	1
100 Gigabit Ethernet	100,000,000 Kbps	100,000/100,000,000	1

Chapter 9

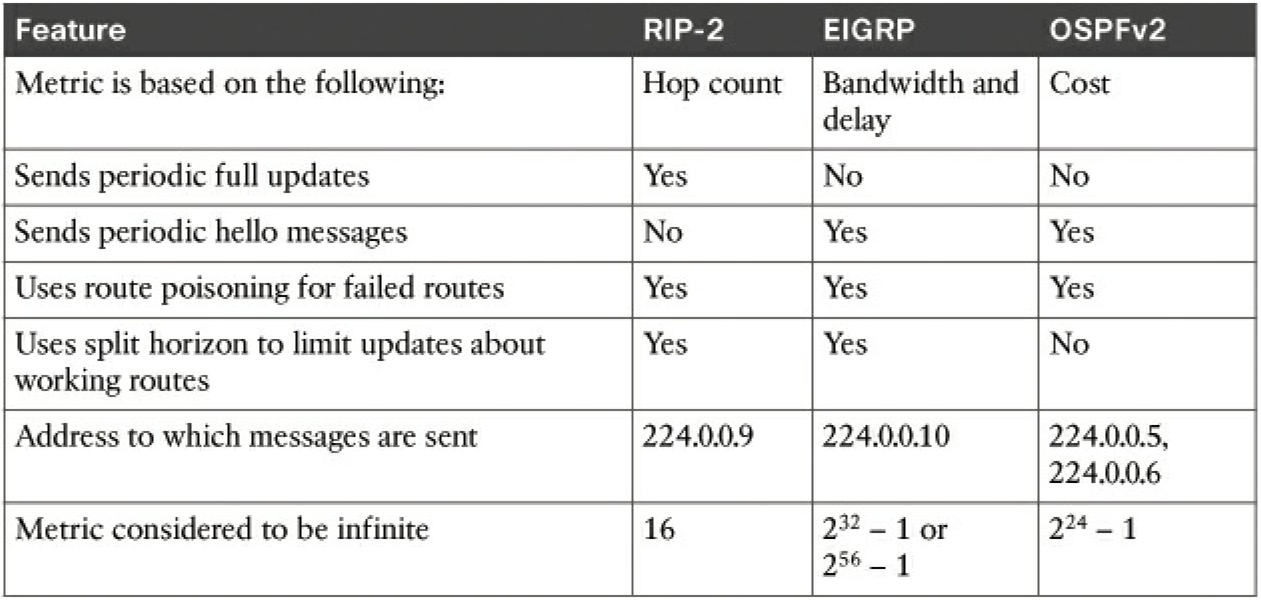
Table 9-2. Interior IP Routing Protocols Compared



Feature	RIP-2	EIGRP	OSPF
Classless/supports VLSM	Yes	Yes	Yes
Distance vector (DV) or link state (LS)	DV	DV[1]	LS
Originally Cisco proprietary	No	Yes	No
Default metrics based at least partially on link bandwidth	No	Yes	Yes
Convergence	Slow	Fast	Fast
Requires the added complexity of areas	No	No	Yes
Supports manual route summarization	Yes	Yes	Yes
Routing updates are sent to a multicast IP address	Yes	Yes	Yes

[1] EIGRP is often described as a balanced hybrid routing protocol, instead of link-state or distance vector. Some documents refer to EIGRP as an advanced distance vector protocol.

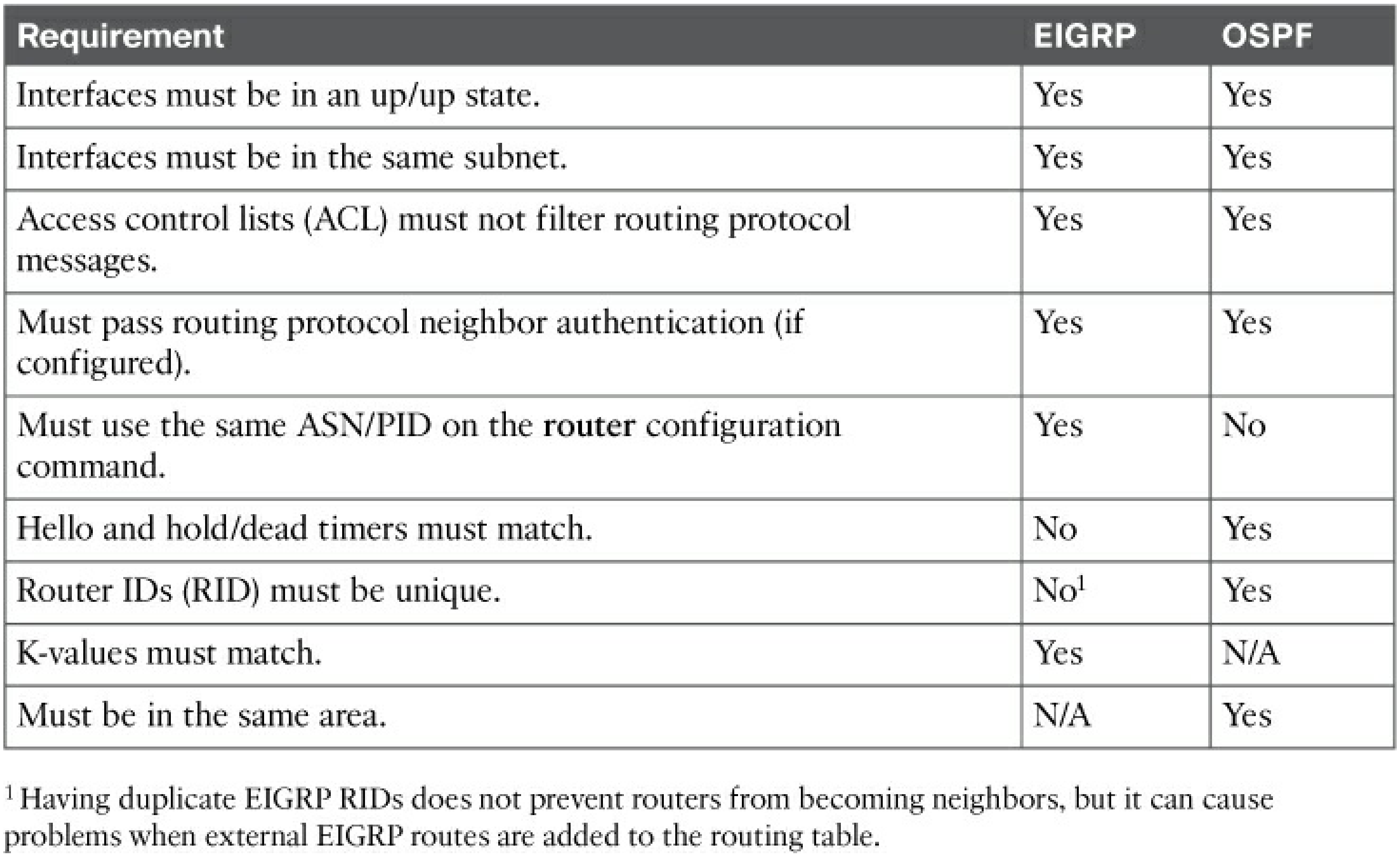
Table 9-3. Interior IP Routing Protocols Compared



Feature	RIP-2	EIGRP	OSPFv2
Metric is based on the following:	Hop count	Bandwidth and delay	Cost
Sends periodic full updates	Yes	No	No
Sends periodic hello messages	No	Yes	Yes
Uses route poisoning for failed routes	Yes	Yes	Yes
Uses split horizon to limit updates about working routes	Yes	Yes	No
Address to which messages are sent	224.0.0.9	224.0.0.10	224.0.0.5, 224.0.0.6
Metric considered to be infinite	16	$2^{32} - 1$ or $2^{56} - 1$	$2^{24} - 1$

Chapter 11

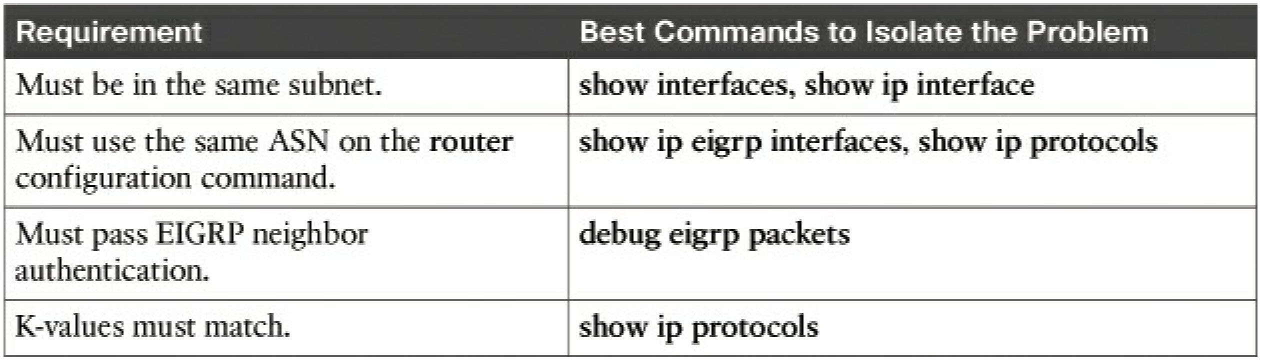
Table 11-2. Neighbor Requirements for EIGRP and OSPF



Requirement	EIGRP	OSPF
Interfaces must be in an up/up state.	Yes	Yes
Interfaces must be in the same subnet.	Yes	Yes
Access control lists (ACL) must not filter routing protocol messages.	Yes	Yes
Must pass routing protocol neighbor authentication (if configured).	Yes	Yes
Must use the same ASN/PID on the **router** configuration command.	Yes	No
Hello and hold/dead timers must match.	No	Yes
Router IDs (RID) must be unique.	No[1]	Yes
K-values must match.	Yes	N/A
Must be in the same area.	N/A	Yes

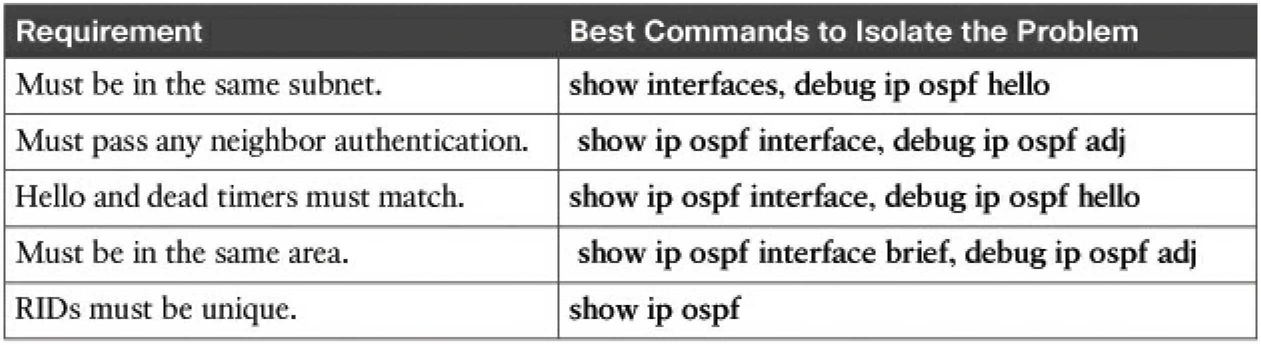
[1] Having duplicate EIGRP RIDs does not prevent routers from becoming neighbors, but it can cause problems when external EIGRP routes are added to the routing table.

Table 11-3. EIGRP Neighbor Requirements and the Best show**/**debug **Commands**



Requirement	Best Commands to Isolate the Problem
Must be in the same subnet.	**show interfaces, show ip interface**
Must use the same ASN on the **router** configuration command.	**show ip eigrp interfaces, show ip protocols**
Must pass EIGRP neighbor authentication.	**debug eigrp packets**
K-values must match.	**show ip protocols**

Table 11-4. OSPF Neighbor Requirements and the Best show**/**debug **Commands**



Requirement	Best Commands to Isolate the Problem
Must be in the same subnet.	**show interfaces, debug ip ospf hello**
Must pass any neighbor authentication.	**show ip ospf interface, debug ip ospf adj**
Hello and dead timers must match.	**show ip ospf interface, debug ip ospf hello**
Must be in the same area.	**show ip ospf interface brief, debug ip ospf adj**
RIDs must be unique.	**show ip ospf**

Chapter 12

Table 12-5. Interface Status Codes and Typical Meanings When a Ping Does Not Work

Line Status	Protocol Status	Likely General Reason/Layer
Administratively down	Down	Interface shutdown
Down	Down	Layer 1
Up	Down	Layer 2
Up	Up	Layer 3

Table 12-6. Likely Reasons for Data Link Problems on Serial Links

Line Status	Protocol Status	Likely Reason
Up	Down on both ends[1]	Mismatched **encapsulation** commands
Up	Down on one end, up on the other	Keepalive disabled on the end in an up state when using HDLC
Up	Down on both ends	PAP/CHAP authentication failure

[1] In this case, the state may flap from up/up, to up/down, to up/up, and so on, while the router keeps trying to make the encapsulation work.

Table 12-7. Summary of Symptoms for Mismatched Subnets on Serial Links

Symptoms When IP Addresses on a Serial Link Are in Different Subnets	HDLC	PPP
Does a ping of the other router's serial IP address work?	No	Yes
Can routing protocols exchange routes over the link?	No	No

Chapter 13

Table 13-3. Frame Relay LMI Types

Name	Document	IOS LMI-Type Parameter
Cisco	Proprietary	**cisco**
ANSI	T1.617 Annex D	**ansi**
ITU	Q.933 Annex A	**q933a**

Chapter 14

Table 14-3. PVC Status Values

Status	Active	Inactive	Deleted	Static
The PVC is defined to the Frame Relay network.	Yes	Yes	No	Unknown
The router will attempt to send frames on a VC in this state.	Yes	No	No	Yes

Chapter 15

Table 15-3. Key Comparison Points for Ethernet WAN, Frame Relay, and Leased Lines

	Leased Line	Frame Relay	Ethernet WAN
Typical physical access links	TDM (T1, E1, and so on)	TDM (T1, E1, and so on)	Ethernet (fiber)
Router interface	Serial	Serial	Ethernet
Protocols	HDLC, PPP[1]	Frame Relay	Ethernet
WAN service promise	Deliver bits to other end of line	Deliver FR frames to other end of each PVC	Deliver Ethernet frames to specific endpoints

[1] The leased line service does not require or use a data link protocol. However, routers typically use HDLC or PPP.

Table 15-4. Key Comparison Points for Ethernet WAN, Frame Relay, and MPLS

	MPLS	Frame Relay	Ethernet WAN
Physical access links	Any that support IP	TDM (T1, E1, and so on)	Ethernet (fiber)
Router interface	Any that support IP	Serial	Ethernet
Protocols	Any that support IP	Frame Relay	Ethernet
WAN service promise	Deliver IP packets	Deliver FR frames	Deliver Ethernet frames

Table 15-5. Comparison of Internet Access Technologies

	Analog Modem	ISDN
Physical access link	Phone line (local loop)	Phone line (local loop)
Internet is always on?	No	No
Data service promise	Send bits to any called party	Send bits to any called party
Speed (general)	56 Kbps	128 Kbps
Asymmetric?	No	No

Table 15-6. Comparison of Internet Access Technologies

	Analog Modem	ISDN	DSL	Cable
Physical access link	Phone line (local loop)	Phone line (local loop)	Phone line (local loop)	CATV Cable
Internet is always on?	No	No	Yes	Yes
Data service promise	Send bits to any called party	Send bits to any called party	Send all data to the ISP	Send data to the ISP
Speed (general)	56 Kbps	128 Kbps	10s of Mbps	10s of Mbps
Asymmetric?	No	No	Yes	Yes

Chapter 16

Table 16-1. Summary of IPv6 Unicast Address Types

Type	First Digits	Similar to IPv4 Public or Private?
Global unicast	2 or 3[1]	Public
Unique local unicast	FD	Private
Link-local	FE80	Neither

[1] IANA actually defines the global unicast address range as any address not otherwise reserved for some other purpose. However, actual address assignments normally happen from 2000::/3 because that was the original range used for these addresses. Many IPv6 references simply quote 2000::/3 as the prefix, which means the first hex digit is either a 2 or 3.

Chapter 17

Table 17-2. Neighbor Requirements for OSPFv2 and OSPFv3

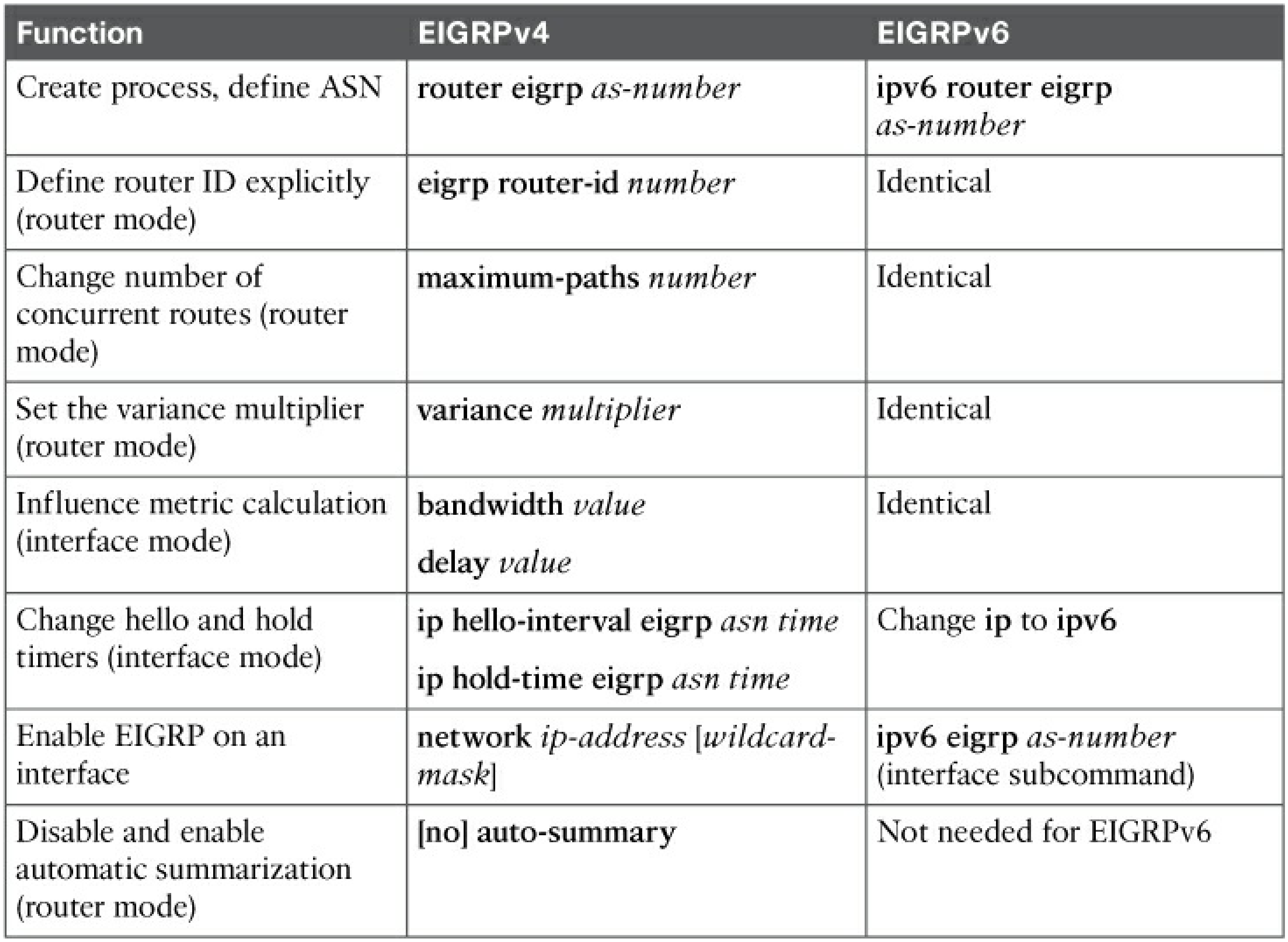
Requirement	OSPFv2	OSPFv3
Interfaces must be in an up/up state.	Yes	Yes
Interfaces must be in the same subnet.	Yes	No
ACLs must not filter routing protocol messages.	Yes	Yes
Must pass routing protocol neighbor authentication (if configured).	Yes	Yes
Hello and dead timers must match.	Yes	Yes
Router IDs must be unique.	Yes	Yes
Must use the same process ID on the **router** configuration command.	No	No

Table 17-3. OSPF Neighbor Requirements and the Best `show`**/**`debug` **Commands**

Requirement	Best Commands to Isolate the Problem
Must pass any neighbor authentication.	**show ipv6 ospf interface**
Hello and dead timers must match.	**show ipv6 ospf interface**
Must be in the same area.	**show ipv6 ospf interface brief,** **show ipv6 protocols**
Router IDs must be unique.	**show ipv6 ospf**
Interfaces must not be passive.	**show ipv6 ospf interface**

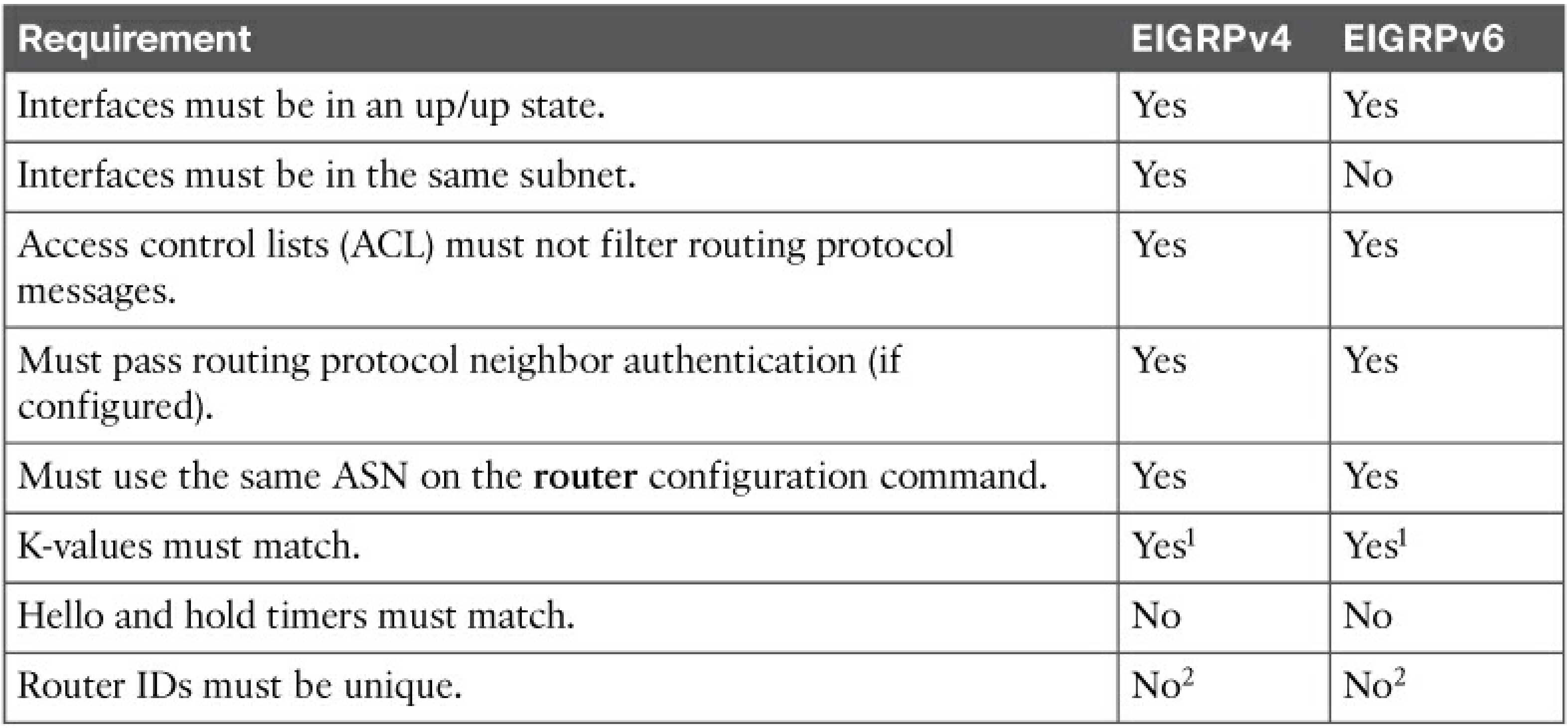
Chapter 18

Table 18-2. Comparison of EIGRPv4 and EIGRPv6 Configuration Commands



Function	EIGRPv4	EIGRPv6
Create process, define ASN	**router eigrp** *as-number*	**ipv6 router eigrp** *as-number*
Define router ID explicitly (router mode)	**eigrp router-id** *number*	Identical
Change number of concurrent routes (router mode)	**maximum-paths** *number*	Identical
Set the variance multiplier (router mode)	**variance** *multiplier*	Identical
Influence metric calculation (interface mode)	**bandwidth** *value* **delay** *value*	Identical
Change hello and hold timers (interface mode)	**ip hello-interval eigrp** *asn time* **ip hold-time eigrp** *asn time*	Change **ip** to **ipv6**
Enable EIGRP on an interface	**network** *ip-address* [*wildcard-mask*]	**ipv6 eigrp** *as-number* (interface subcommand)
Disable and enable automatic summarization (router mode)	**[no] auto-summary**	Not needed for EIGRPv6

Table 18-3. Neighbor Requirements for EIGRPv4 and EIGRPv6



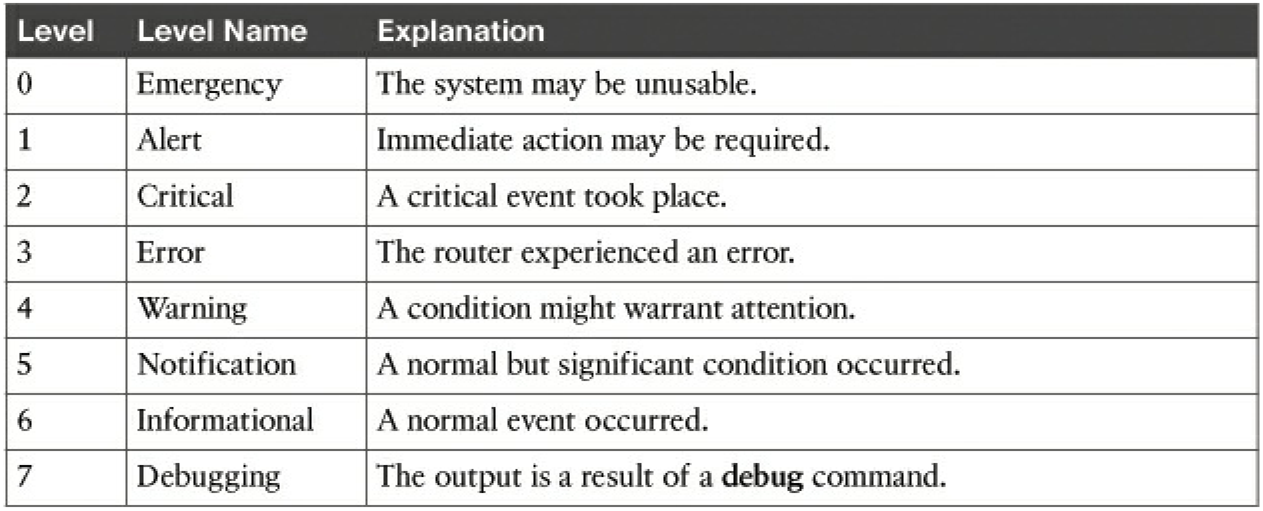
Requirement	EIGRPv4	EIGRPv6
Interfaces must be in an up/up state.	Yes	Yes
Interfaces must be in the same subnet.	Yes	No
Access control lists (ACL) must not filter routing protocol messages.	Yes	Yes
Must pass routing protocol neighbor authentication (if configured).	Yes	Yes
Must use the same ASN on the **router** configuration command.	Yes	Yes
K-values must match.	Yes[1]	Yes[1]
Hello and hold timers must match.	No	No
Router IDs must be unique.	No[2]	No[2]

[1] K values define the EIGRP metric calculation algorithm. This book does not discuss how to change these settings, and Cisco recommends that the settings be left as is.

[2] Having duplicate EIGRP RIDs does not prevent routers from becoming neighbors, but it can cause problems when external EIGRP routes are added to the routing table.

Chapter 19

Table 19-3. System Message Severity Levels



Level	Level Name	Explanation
0	Emergency	The system may be unusable.
1	Alert	Immediate action may be required.
2	Critical	A critical event took place.
3	Error	The router experienced an error.
4	Warning	A condition might warrant attention.
5	Notification	A normal but significant condition occurred.
6	Informational	A normal event occurred.
7	Debugging	The output is a result of a **debug** command.

Appendix F. Mind Map Solutions

This appendix provides solutions to the mind map exercises in the "Part Review" sections. You can also find files of these solutions in PDF and XMIND format on the DVD. (The sample mind maps on the download page use the XMIND application [www.xmind.net], which at the time of publication supported free versions on Windows, Mac, and Linux.)

Part I Review Mind Map Solution

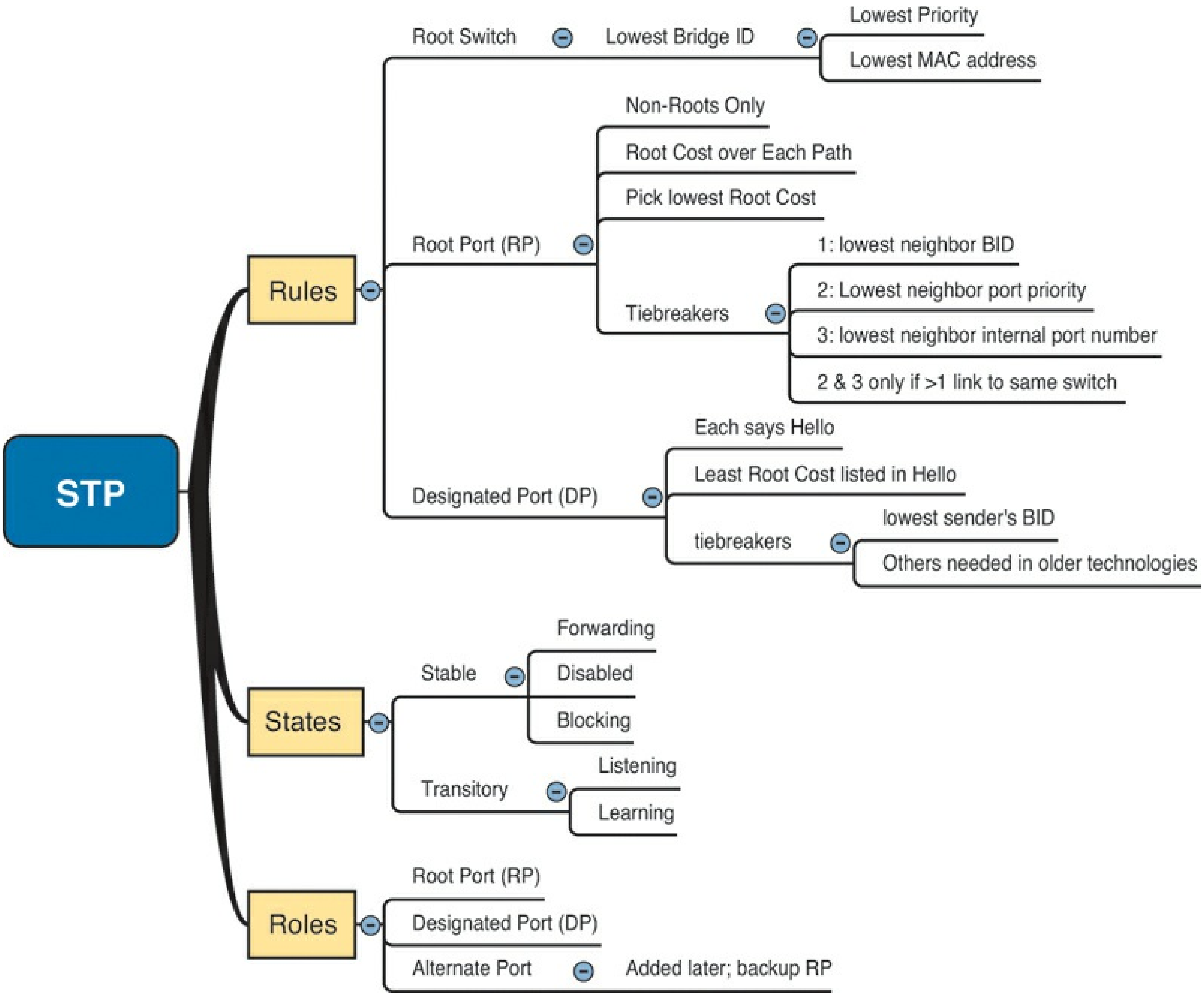

STP
Rules
Root Switch
Lowest Bridge ID
Lowest Priority
Lowest MAC address
Root Port (RP)
Non-Roots Only
Root Cost over Each Path
Pick lowest Root Cost
Tiebreakers
1: lowest neighbor BID
2: Lowest neighbor port priority
3: lowest neighbor internal port number
2 & 3 only if >1 link to same switch
Designated Port (DP)
Each says Hello
Least Root Cost listed in Hello
tiebreakers
lowest sender's BID
Others needed in older technologies
States
Stable
Forwarding
Disabled
Blocking
Transitory
Listening
Learning
Roles
Root Port (RP)
Designated Port (DP)
Alternate Port
Added later; backup RP

Figure F-1. Part I Review Mind Map Solution

Part II Review Mind Map Solutions

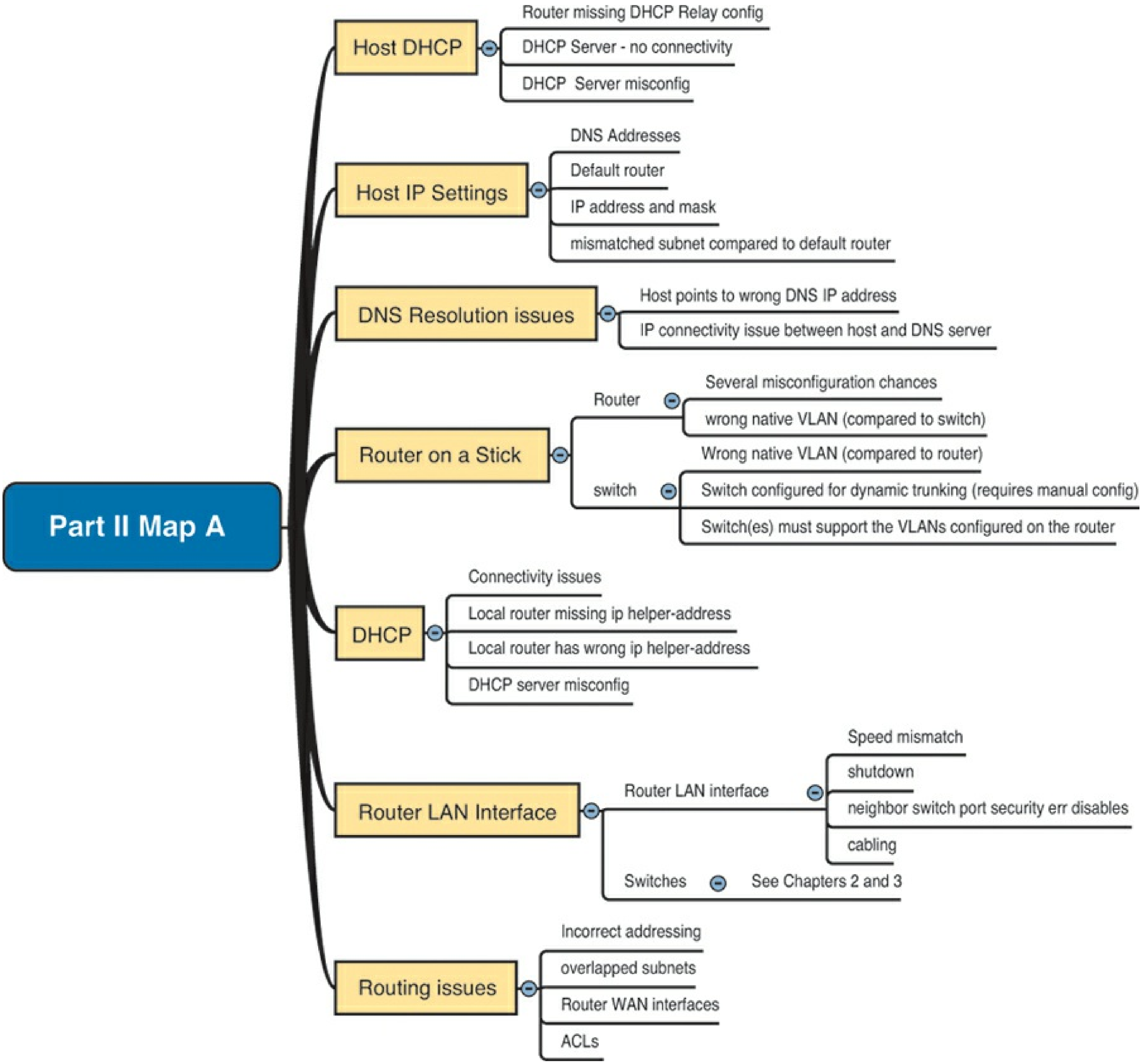

Part II Map A
Host DHCP
Router missing DHCP Relay config
DHCP Server - no connectivity
DHCP Server misconfig
Host IP Settings
DNS Addresses
Default router
IP address and mask
mismatched subnet compared to default router
DNS Resolution issues
Host points to wrong DNS IP address
IP connectivity issue between host and DNS server
Router on a Stick
Router
Several misconfiguration chances
wrong native VLAN (compared to switch)
switch
Wrong native VLAN (compared to router)
Switch configured for dynamic trunking (requires manual config)
Switch(es) must support the VLANs configured on the router
DHCP
Connectivity issues
Local router missing ip helper-address
Local router has wrong ip helper-address
DHCP server misconfig
Router LAN Interface
Router LAN interface
Speed mismatch
shutdown
neighbor switch port security err disables
cabling
Switches
See Chapters 2 and 3
Routing issues
Incorrect addressing
overlapped subnets
Router WAN interfaces
ACLs

Figure F-2. Part II Review Mind Map Solution A

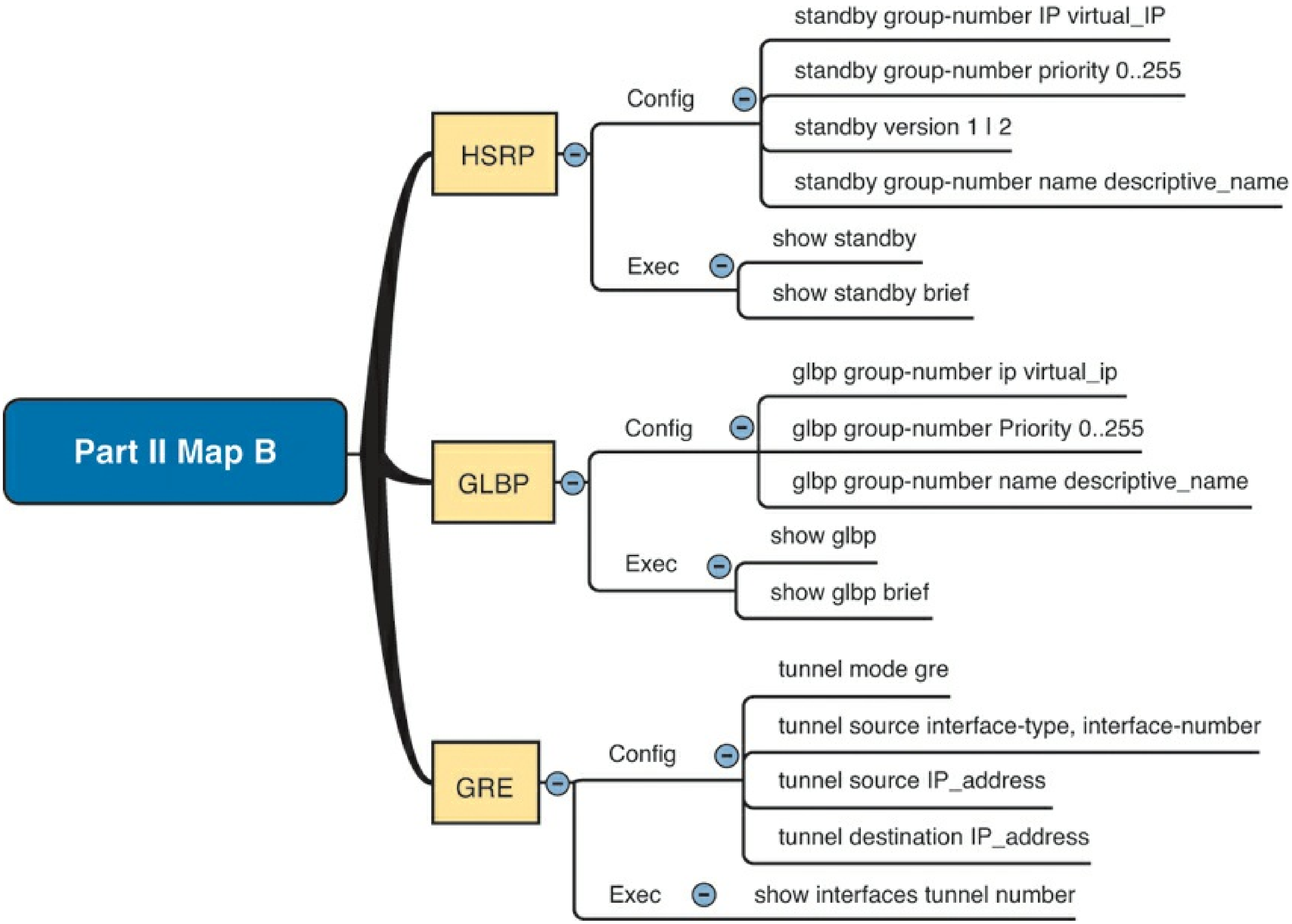

Part II Map B
HSRP
Config
standby group-number IP virtual_IP
standby group-number priority 0..255
standby version 1 I 2
standby group-number name descriptive_name
Exec
show standby
show standby brief
GLBP
Config
glbp group-number ip virtual_ip
glbp group-number Priority 0..255
glbp group-number name descriptive_name
Exec
show glbp
show glbp brief
GRE
Config
tunnel mode gre
tunnel source interface-type, interface-number
tunnel source IP_address
tunnel destination IP_address
Exec
show interfaces tunnel number

Figure F-3. Part II Review Mind Map Solution B

Part III Review Mind Map Solutions

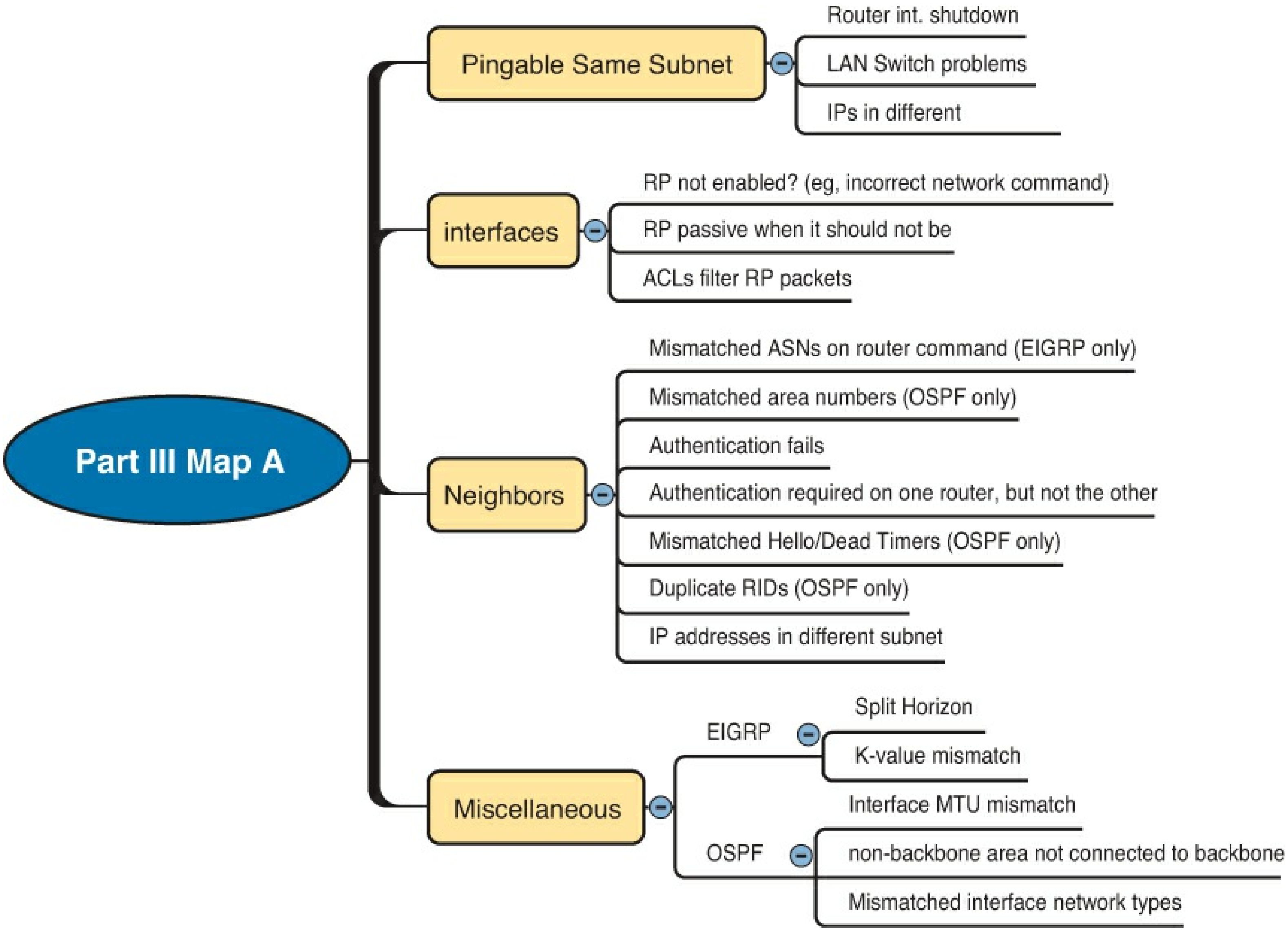

Part III Map A
Pingable Same Subnet
Router int. shutdown
LAN Switch problems
IPs in different
interfaces
RP not enabled? (eg, incorrect network command)
RP passive when it should not be
ACLs filter RP packets
Neighbors
Mismatched ASNs on router command (EIGRP only)
Mismatched area numbers (OSPF only)
Authentication fails
Authentication required on one router, but not the other
Mismatched Hello/Dead Timers (OSPF only)
Duplicate RIDs (OSPF only)
IP addresses in different subnet
Miscellaneous
EIGRP
Split Horizon
K-value mismatch
OSPF
Interface MTU mismatch
non-backbone area not connected to backbone
Mismatched interface network types

Figure F-4. Part III Review Mind Map Solution A

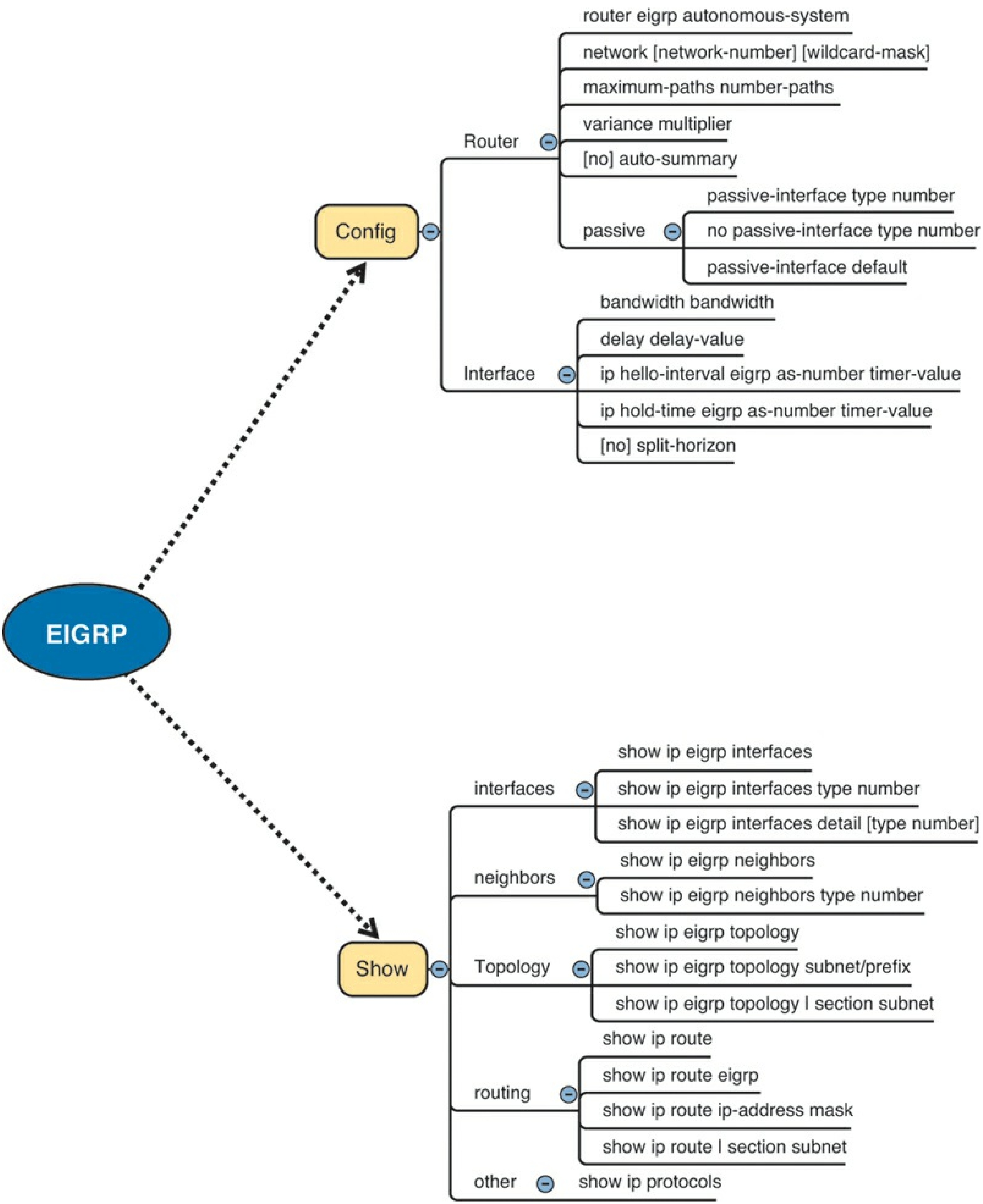

EIGRP
Config
Router
router eigrp autonomous-system
network [network-number] [wildcard-mask]
maximum-paths number-paths
variance multiplier
[no] auto-summary
passive
passive-interface type number
no passive-interface type number
passive-interface default
Interface
bandwidth bandwidth
delay delay-value
ip hello-interval eigrp as-number timer-value
ip hold-time eigrp as-number timer-value
[no] split-horizon
Show
interfaces
show ip eigrp interfaces
show ip eigrp interfaces type number
show ip eigrp interfaces detail [type number]
neighbors
show ip eigrp neighbors
show ip eigrp neighbors type number
Topology
show ip eigrp topology
show ip eigrp topology subnet/prefix
show ip eigrp topology | section subnet
routing
show ip route
show ip route eigrp
show ip route ip-address mask
show ip route | section subnet
other
show ip protocols

Figure F-5. Part III Review Mind Map Solution B, EIGRP

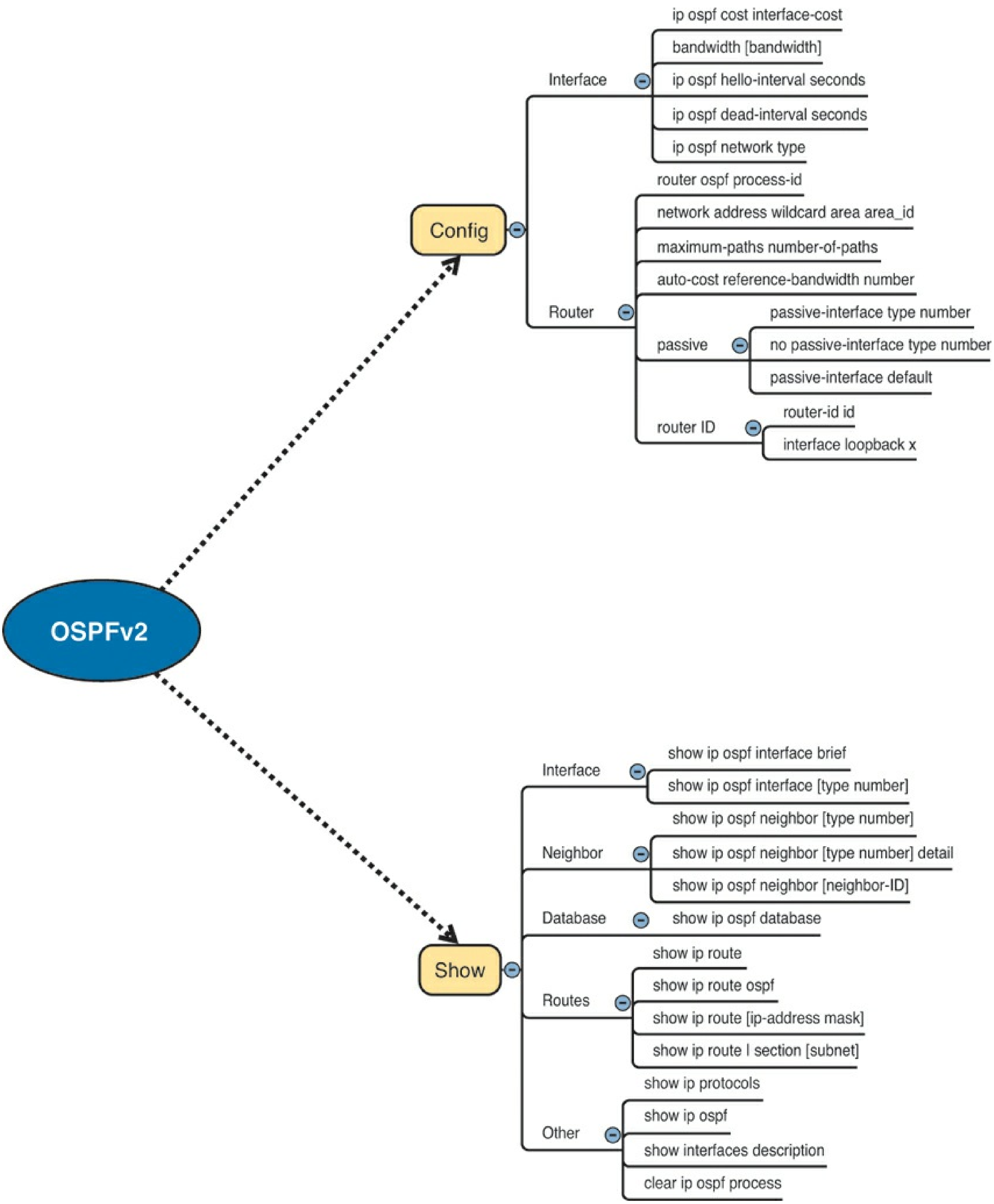

OSPFv2
Config
Interface
ip ospf cost interface-cost
bandwidth [bandwidth]
ip ospf hello-interval seconds
ip ospf dead-interval seconds
ip ospf network type
Router
router ospf process-id
network address wildcard area area_id
maximum-paths number-of-paths
auto-cost reference-bandwidth number
passive
passive-interface type number
no passive-interface type number
passive-interface default
router ID
router-id id
interface loopback x
Show
Interface
show ip ospf interface brief
show ip ospf interface [type number]
Neighbor
show ip ospf neighbor [type number]
show ip ospf neighbor [type number] detail
show ip ospf neighbor [neighbor-ID]
Database
show ip ospf database
Routes
show ip route
show ip route ospf
show ip route [ip-address mask]
show ip route | section [subnet]
Other
show ip protocols
show ip ospf
show interfaces description
clear ip ospf process

Figure F-6. Part III Review Mind Map Solution B, OSPF

Part IV Review Mind Map Solutions

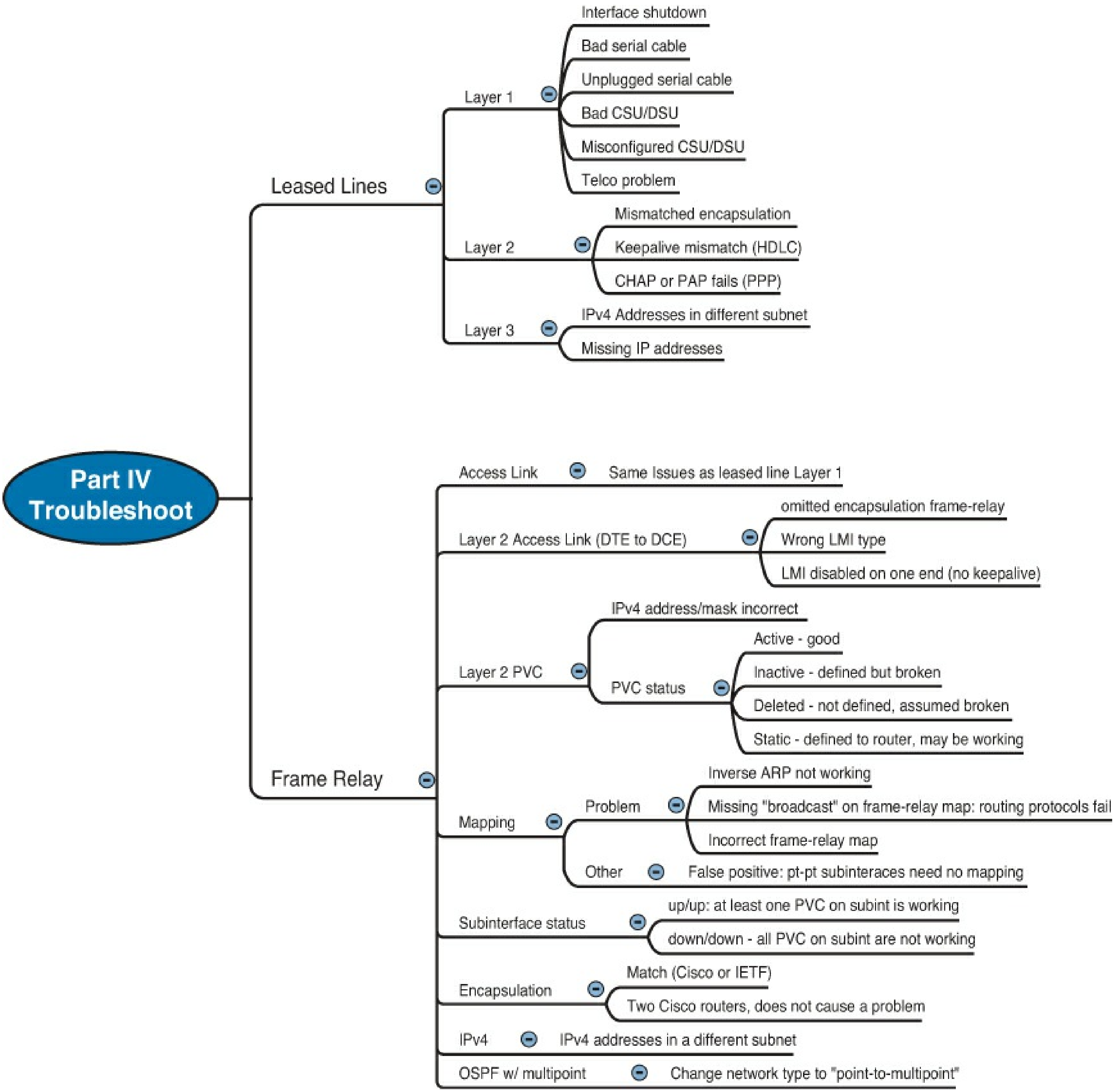

Part IV Troubleshoot
Leased Lines
Layer 1
Interface shutdown
Bad serial cable
Unplugged serial cable
Bad CSU/DSU
Misconfigured CSU/DSU
Telco problem
Layer 2
Mismatched encapsulation
Keepalive mismatch (HDLC)
CHAP or PAP fails (PPP)
Layer 3
IPv4 Addresses in different subnet
Missing IP addresses
Frame Relay
Access Link
Same Issues as leased line Layer 1
Layer 2 Access Link (DTE to DCE)
omitted encapsulation frame-relay
Wrong LMI type
LMI disabled on one end (no keepalive)
Layer 2 PVC
IPv4 address/mask incorrect
PVC status
Active - good
Inactive - defined but broken
Deleted - not defined, assumed broken
Static - defined to router, may be working
Mapping
Problem
Inverse ARP not working
Missing "broadcast" on frame-relay map: routing protocols fail
Incorrect frame-relay map
Other
False positive: pt-pt subinteraces need no mapping
Subinterface status
up/up: at least one PVC on subint is working
down/down - all PVC on subint are not working
Encapsulation
Match (Cisco or IETF)
Two Cisco routers, does not cause a problem
IPv4
IPv4 addresses in a different subnet
OSPF w/ multipoint
Change network type to "point-to-multipoint"

Figure F-7. Part IV Review Mind Map Solution A

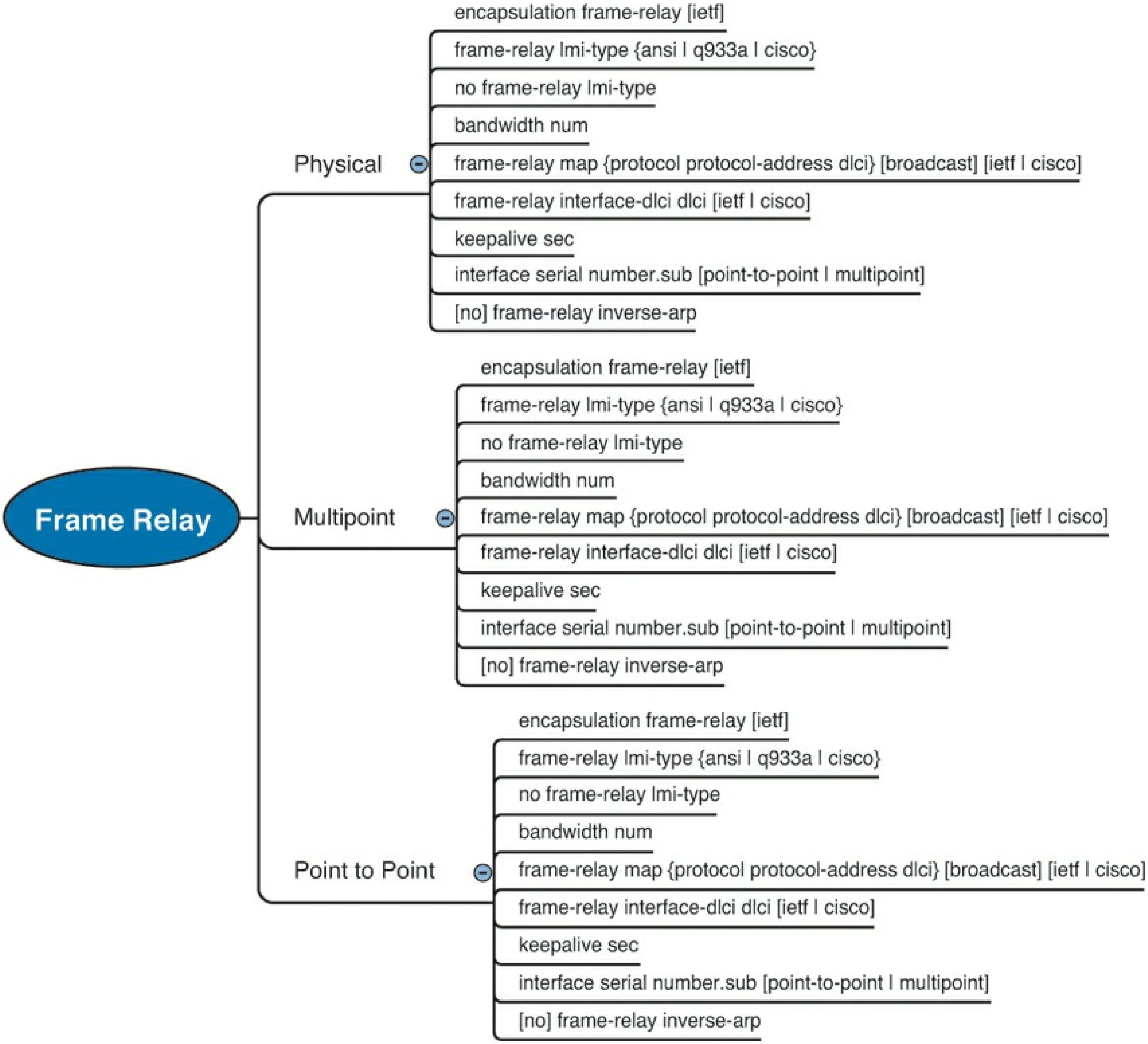

Frame Relay
Physical
encapsulation frame-relay [ietf]
frame-relay lmi-type {ansi | q933a | cisco}
no frame-relay lmi-type
bandwidth num
frame-relay map {protocol protocol-address dlci} [broadcast] [ietf | cisco]
frame-relay interface-dlci dlci [ietf | cisco]
keepalive sec
interface serial number.sub [point-to-point | multipoint]
[no] frame-relay inverse-arp
Multipoint
encapsulation frame-relay [ietf]
frame-relay lmi-type {ansi | q933a | cisco}
no frame-relay lmi-type
bandwidth num
frame-relay map {protocol protocol-address dlci} [broadcast] [ietf | cisco]
frame-relay interface-dlci dlci [ietf | cisco]
keepalive sec
interface serial number.sub [point-to-point | multipoint]
[no] frame-relay inverse-arp
Point to Point
encapsulation frame-relay [ietf]
frame-relay lmi-type {ansi | q933a | cisco}
no frame-relay lmi-type
bandwidth num
frame-relay map {protocol protocol-address dlci} [broadcast] [ietf | cisco]
frame-relay interface-dlci dlci [ietf | cisco]
keepalive sec
interface serial number.sub [point-to-point | multipoint]
[no] frame-relay inverse-arp

Figure F-8. Part IV Review Mind Map Solution, Frame Relay

Part V Review Mind Map Solutions

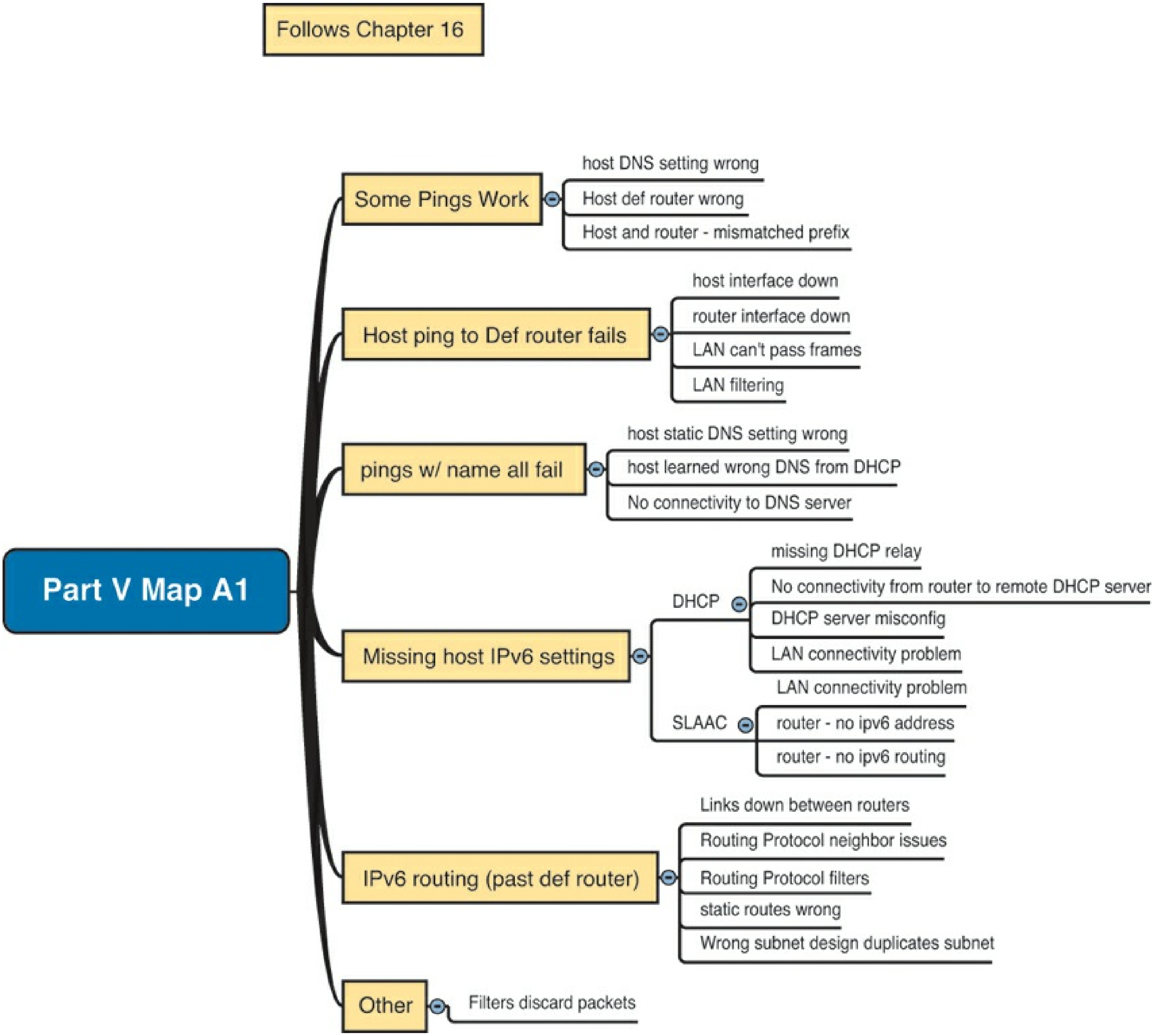

Follows Chapter 16
Part V Map A1
Some Pings Work
host DNS setting wrong
Host def router wrong
Host and router - mismatched prefix
Host ping to Def router fails
host interface down
router interface down
LAN can't pass frames
LAN filtering
pings w/ name all fail
host static DNS setting wrong
host learned wrong DNS from DHCP
No connectivity to DNS server
Missing host IPv6 settings
DHCP
missing DHCP relay
No connectivity from router to remote DHCP server
DHCP server misconfig
LAN connectivity problem
SLAAC
LAN connectivity problem
router - no ipv6 address
router - no ipv6 routing
IPv6 routing (past def router)
Links down between routers
Routing Protocol neighbor issues
Routing Protocol filters
static routes wrong
Wrong subnet design duplicates subnet
Other
Filters discard packets

Figure F-9. Part V Review Mind Map Solution, A1

Follows Chapter 17

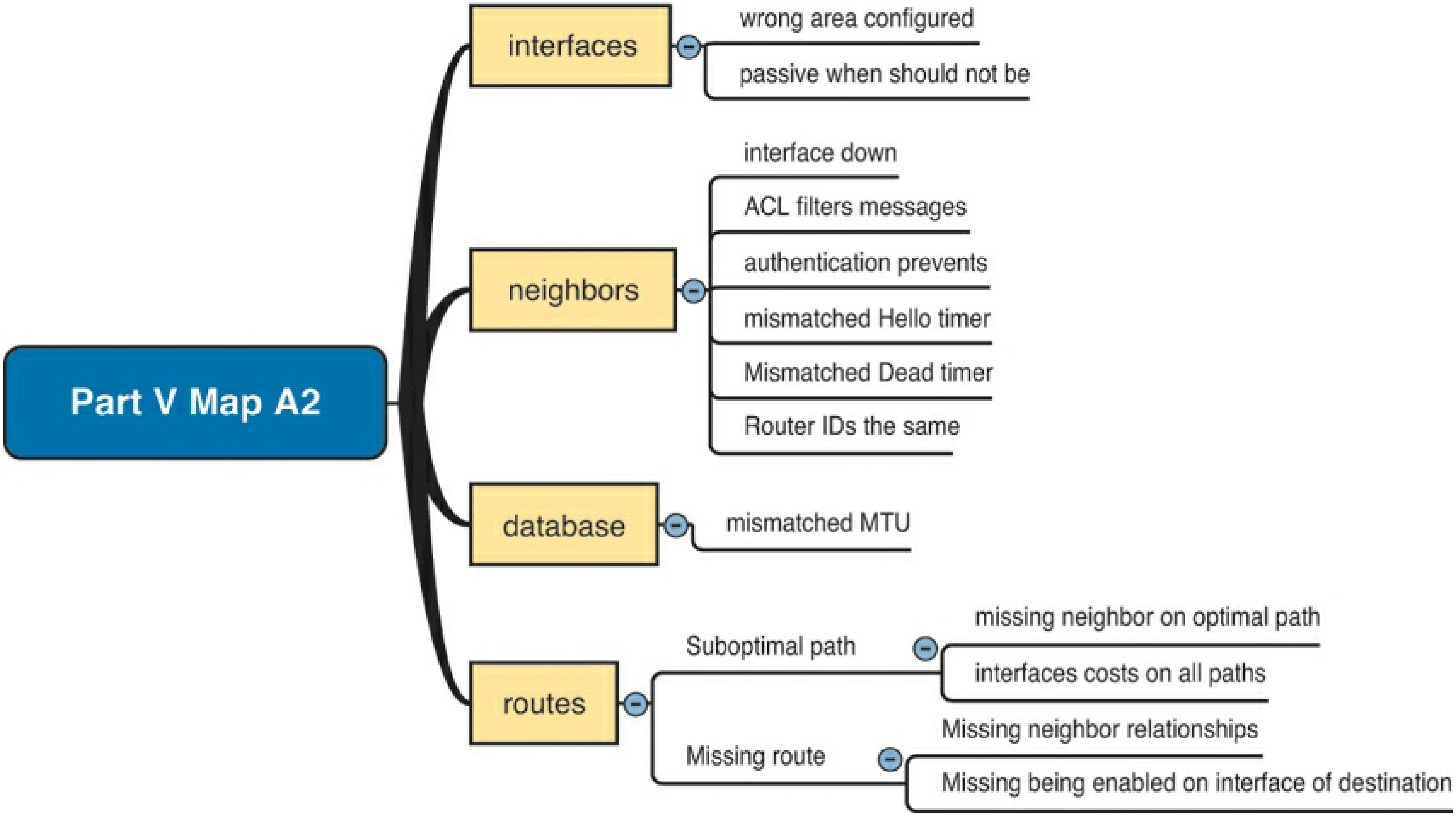

Part V Map A2
interfaces
wrong area configured
passive when should not be
neighbors
interface down
ACL filters messages
authentication prevents
mismatched Hello timer
Mismatched Dead timer
Router IDs the same
database
mismatched MTU
routes
Suboptimal path
missing neighbor on optimal path
interfaces costs on all paths
Missing route
Missing neighbor relationships
Missing being enabled on interface of destination

Figure F-10. Part V Review Mind Map Solution, A2

Follows Chapter 18

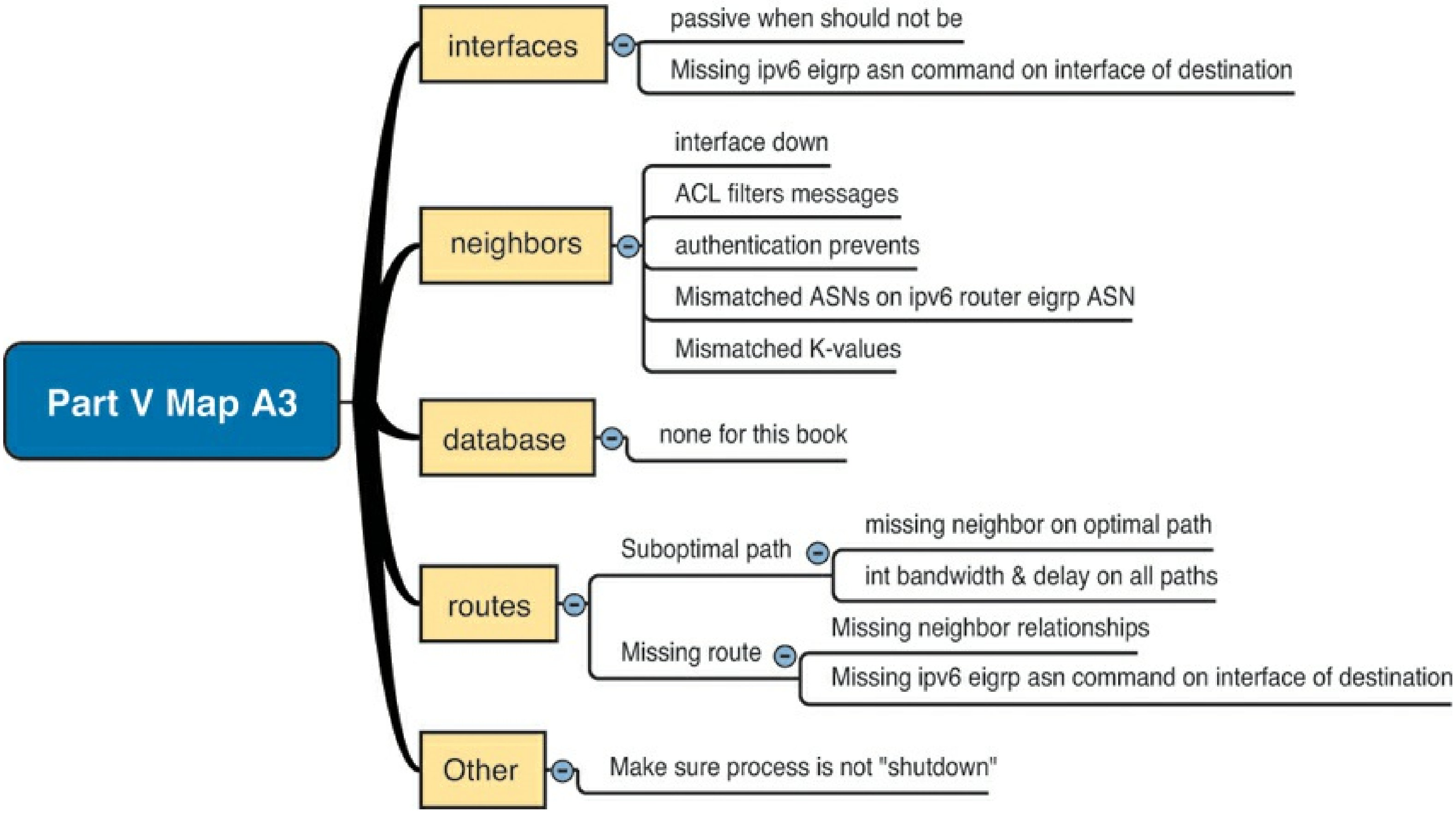

Part V Map A3
interfaces
passive when should not be
Missing ipv6 eigrp asn command on interface of destination
neighbors
interface down
ACL filters messages
authentication prevents
Mismatched ASNs on ipv6 router eigrp ASN
Mismatched K-values
database
none for this book
routes
Suboptimal path
missing neighbor on optimal path
int bandwidth & delay on all paths
Missing route
Missing neighbor relationships
Missing ipv6 eigrp asn command on interface of destination
Other
Make sure process is not "shutdown"

Figure F-11. Part V Review Mind Map Solution, A3

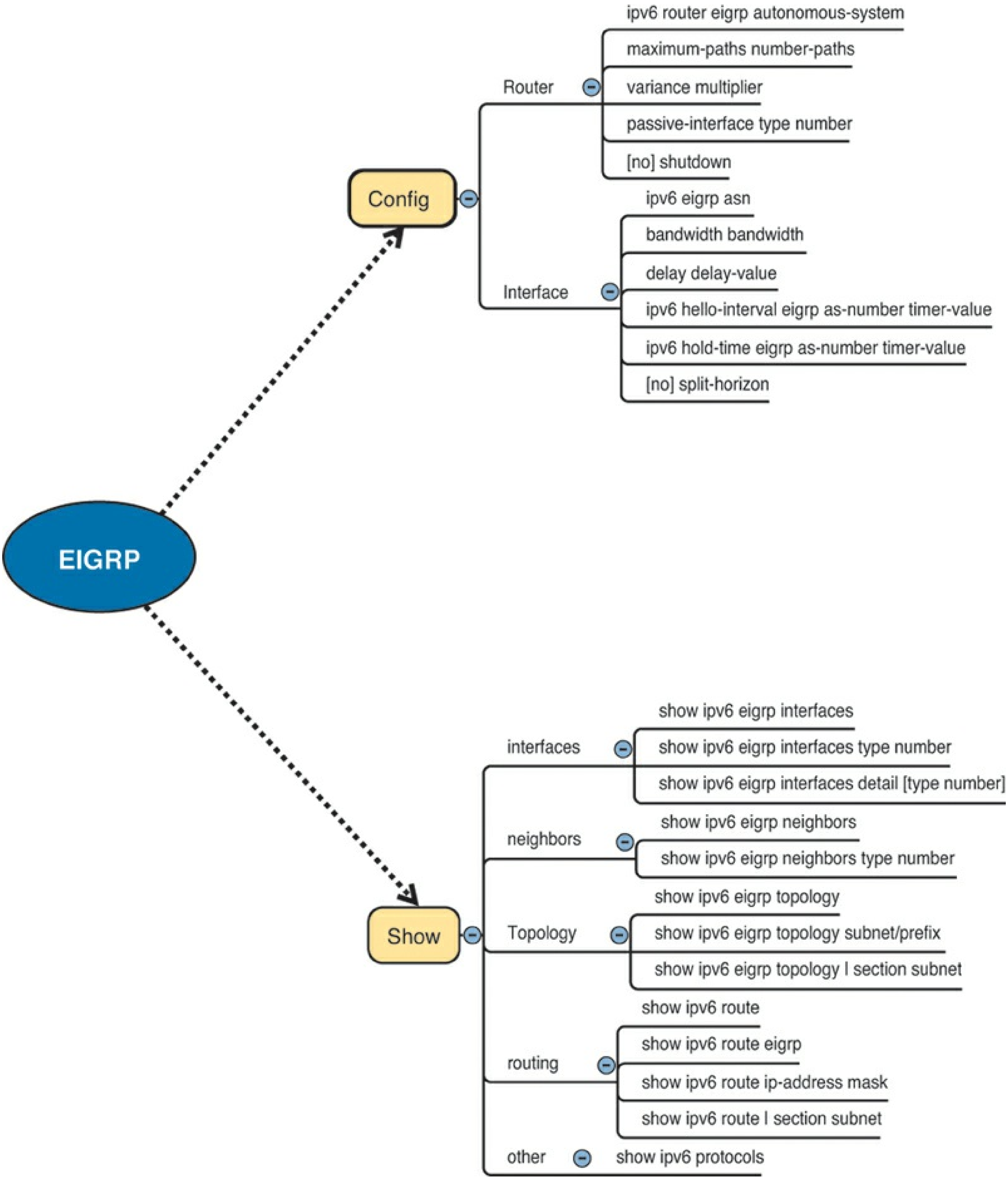

EIGRP
Config
Router
ipv6 router eigrp autonomous-system
maximum-paths number-paths
variance multiplier
passive-interface type number
[no] shutdown
Interface
ipv6 eigrp asn
bandwidth bandwidth
delay delay-value
ipv6 hello-interval eigrp as-number timer-value
ipv6 hold-time eigrp as-number timer-value
[no] split-horizon
Show
interfaces
show ipv6 eigrp interfaces
show ipv6 eigrp interfaces type number
show ipv6 eigrp interfaces detail [type number]
neighbors
show ipv6 eigrp neighbors
show ipv6 eigrp neighbors type number
Topology
show ipv6 eigrp topology
show ipv6 eigrp topology subnet/prefix
show ipv6 eigrp topology I section subnet
routing
show ipv6 route
show ipv6 route eigrp
show ipv6 route ip-address mask
show ipv6 route I section subnet
other
show ipv6 protocols

Figure F-12. Part V Review Mind Map Solution B, EIGRPv6

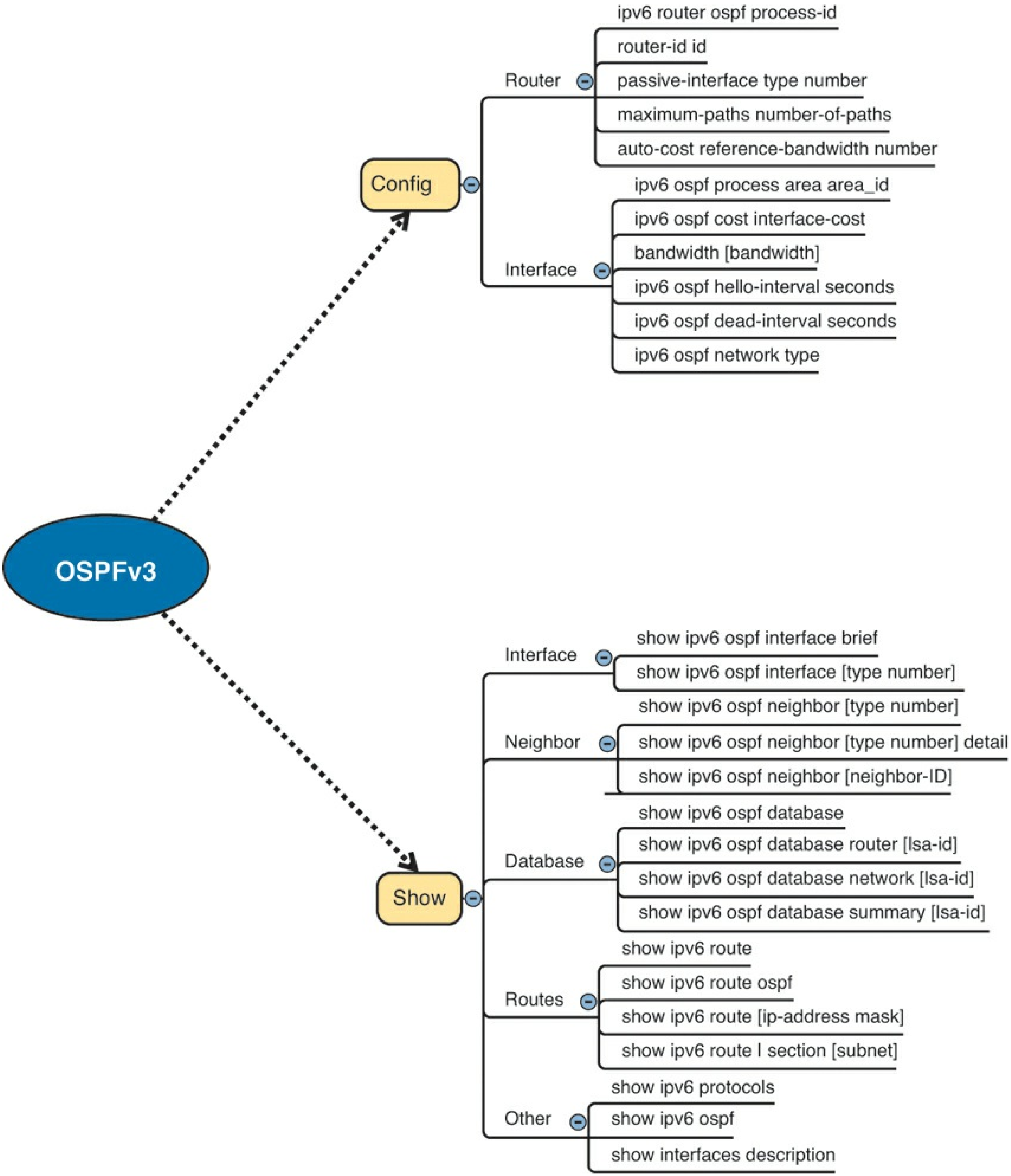
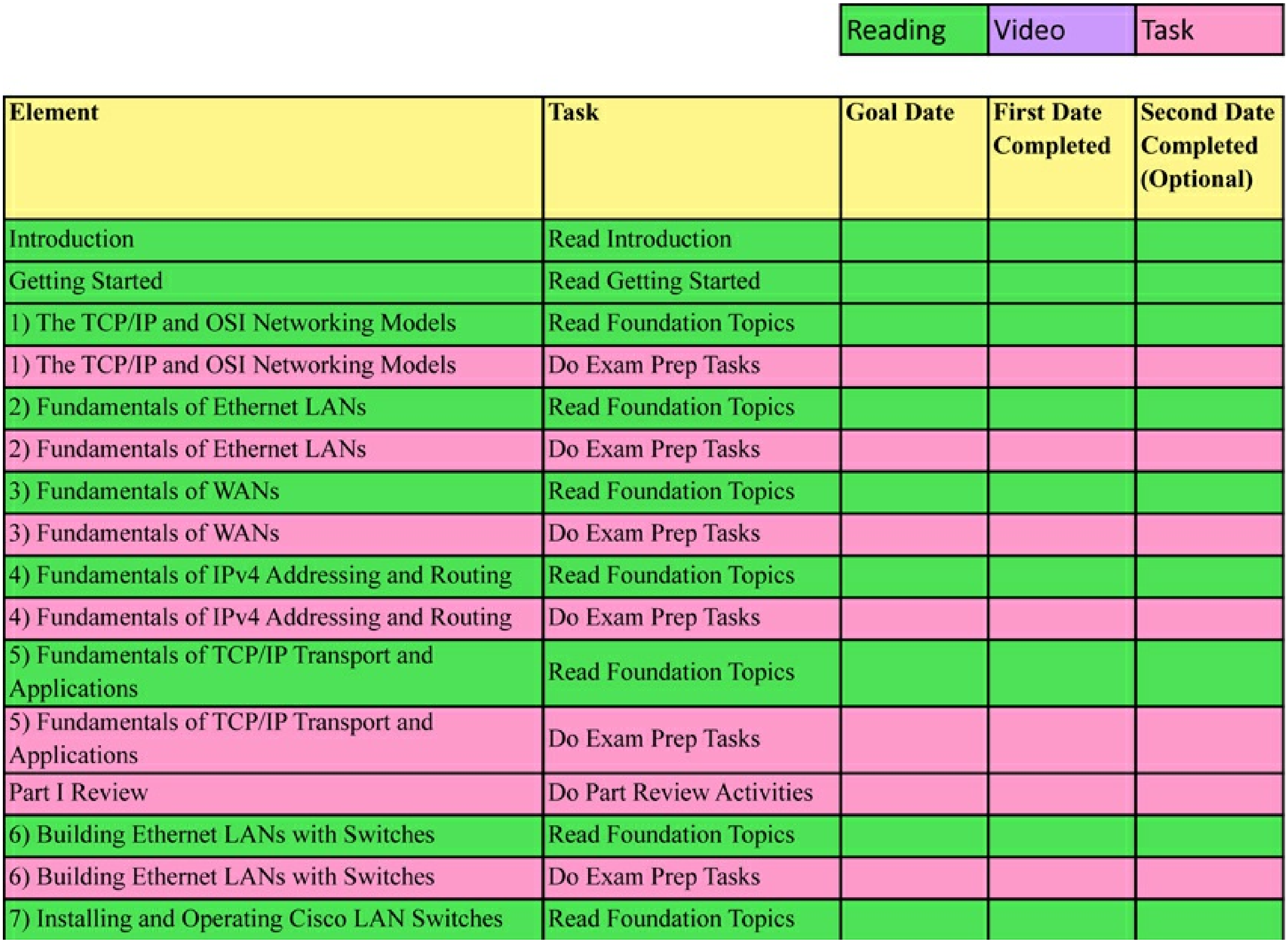

OSPFv3
Config
Router
ipv6 router ospf process-id
router-id id
passive-interface type number
maximum-paths number-of-paths
auto-cost reference-bandwidth number
Interface
ipv6 ospf process area area_id
ipv6 ospf cost interface-cost
bandwidth [bandwidth]
ipv6 ospf hello-interval seconds
ipv6 ospf dead-interval seconds
ipv6 ospf network type
Show
Interface
show ipv6 ospf interface brief
show ipv6 ospf interface [type number]
Neighbor
show ipv6 ospf neighbor [type number]
show ipv6 ospf neighbor [type number] detail
show ipv6 ospf neighbor [neighbor-ID]
Database
show ipv6 ospf database
show ipv6 ospf database router [lsa-id]
show ipv6 ospf database network [lsa-id]
show ipv6 ospf database summary [lsa-id]
Routes
show ipv6 route
show ipv6 route ospf
show ipv6 route [ip-address mask]
show ipv6 route | section [subnet]
Other
show ipv6 protocols
show ipv6 ospf
show interfaces description

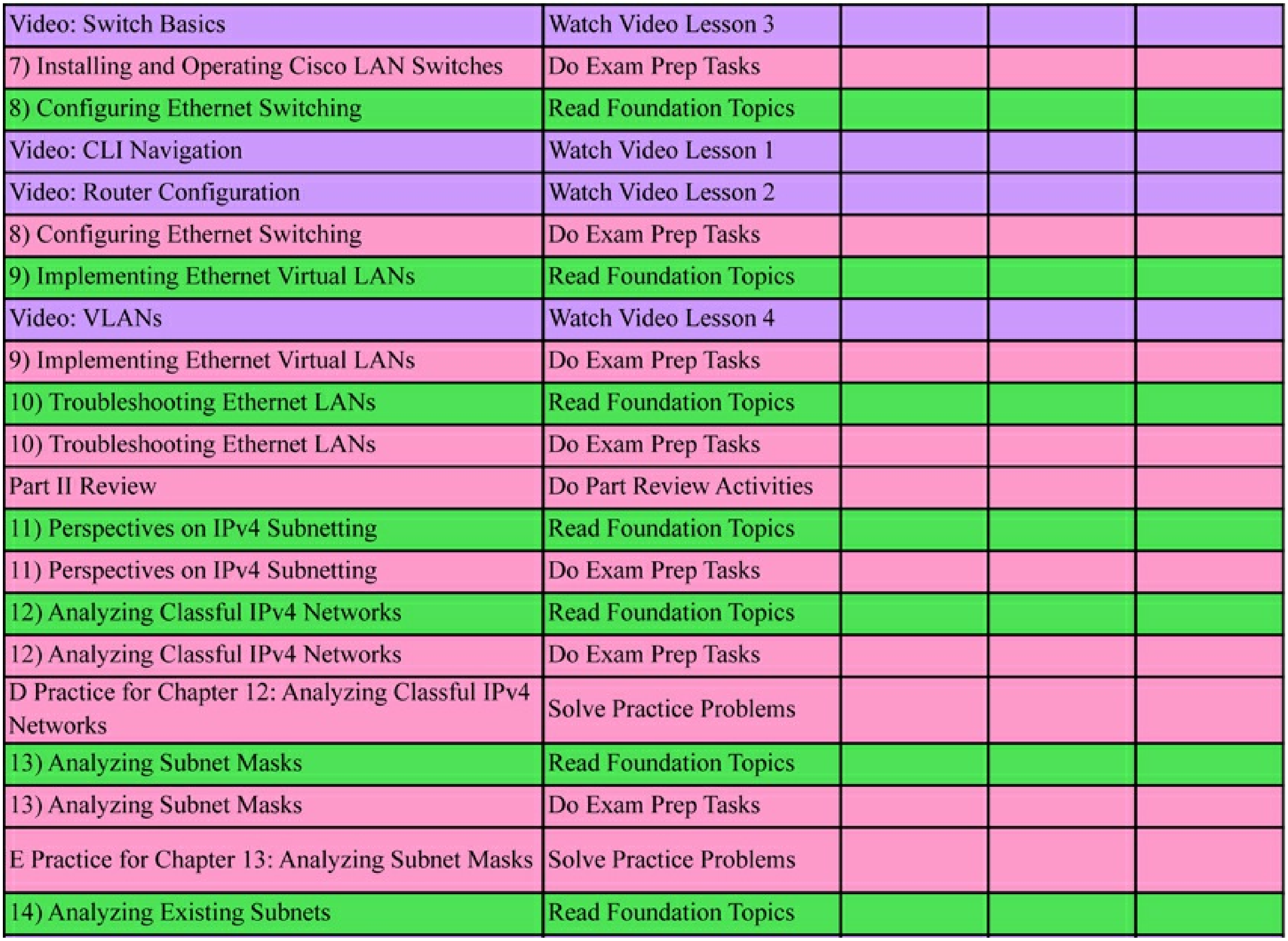
Figure F-13. Part V Review Mind Map Solution B, OSPFv3

Appendix G. Study Planner

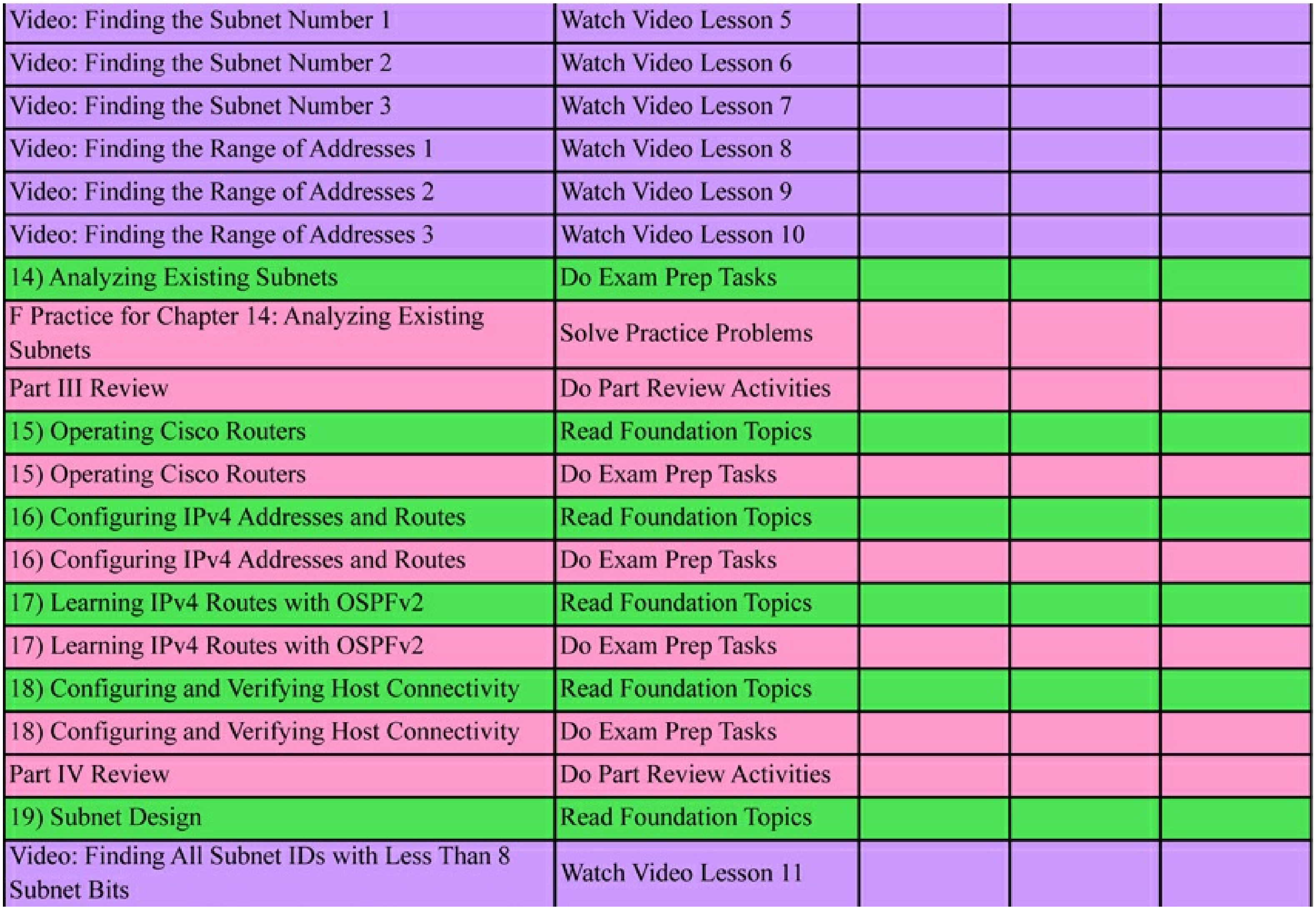


Reading	Video	Task

Element	Task	Goal Date	First Date Completed	Second Date Completed (Optional)
Introduction	Read Introduction			
Getting Started	Read Getting Started			
1) The TCP/IP and OSI Networking Models	Read Foundation Topics			
1) The TCP/IP and OSI Networking Models	Do Exam Prep Tasks			
2) Fundamentals of Ethernet LANs	Read Foundation Topics			
2) Fundamentals of Ethernet LANs	Do Exam Prep Tasks			
3) Fundamentals of WANs	Read Foundation Topics			
3) Fundamentals of WANs	Do Exam Prep Tasks			
4) Fundamentals of IPv4 Addressing and Routing	Read Foundation Topics			
4) Fundamentals of IPv4 Addressing and Routing	Do Exam Prep Tasks			
5) Fundamentals of TCP/IP Transport and Applications	Read Foundation Topics			
5) Fundamentals of TCP/IP Transport and Applications	Do Exam Prep Tasks			
Part I Review	Do Part Review Activities			
6) Building Ethernet LANs with Switches	Read Foundation Topics			
6) Building Ethernet LANs with Switches	Do Exam Prep Tasks			
7) Installing and Operating Cisco LAN Switches	Read Foundation Topics			



Video: Switch Basics	Watch Video Lesson 3			
7) Installing and Operating Cisco LAN Switches	Do Exam Prep Tasks			
8) Configuring Ethernet Switching	Read Foundation Topics			
Video: CLI Navigation	Watch Video Lesson 1			
Video: Router Configuration	Watch Video Lesson 2			
8) Configuring Ethernet Switching	Do Exam Prep Tasks			
9) Implementing Ethernet Virtual LANs	Read Foundation Topics			
Video: VLANs	Watch Video Lesson 4			
9) Implementing Ethernet Virtual LANs	Do Exam Prep Tasks			
10) Troubleshooting Ethernet LANs	Read Foundation Topics			
10) Troubleshooting Ethernet LANs	Do Exam Prep Tasks			
Part II Review	Do Part Review Activities			
11) Perspectives on IPv4 Subnetting	Read Foundation Topics			
11) Perspectives on IPv4 Subnetting	Do Exam Prep Tasks			
12) Analyzing Classful IPv4 Networks	Read Foundation Topics			
12) Analyzing Classful IPv4 Networks	Do Exam Prep Tasks			
D Practice for Chapter 12: Analyzing Classful IPv4 Networks	Solve Practice Problems			
13) Analyzing Subnet Masks	Read Foundation Topics			
13) Analyzing Subnet Masks	Do Exam Prep Tasks			
E Practice for Chapter 13: Analyzing Subnet Masks	Solve Practice Problems			
14) Analyzing Existing Subnets	Read Foundation Topics			



Video: Finding the Subnet Number 1	Watch Video Lesson 5			
Video: Finding the Subnet Number 2	Watch Video Lesson 6			
Video: Finding the Subnet Number 3	Watch Video Lesson 7			
Video: Finding the Range of Addresses 1	Watch Video Lesson 8			
Video: Finding the Range of Addresses 2	Watch Video Lesson 9			
Video: Finding the Range of Addresses 3	Watch Video Lesson 10			
14) Analyzing Existing Subnets	Do Exam Prep Tasks			
F Practice for Chapter 14: Analyzing Existing Subnets	Solve Practice Problems			
Part III Review	Do Part Review Activities			
15) Operating Cisco Routers	Read Foundation Topics			
15) Operating Cisco Routers	Do Exam Prep Tasks			
16) Configuring IPv4 Addresses and Routes	Read Foundation Topics			
16) Configuring IPv4 Addresses and Routes	Do Exam Prep Tasks			
17) Learning IPv4 Routes with OSPFv2	Read Foundation Topics			
17) Learning IPv4 Routes with OSPFv2	Do Exam Prep Tasks			
18) Configuring and Verifying Host Connectivity	Read Foundation Topics			
18) Configuring and Verifying Host Connectivity	Do Exam Prep Tasks			
Part IV Review	Do Part Review Activities			
19) Subnet Design	Read Foundation Topics			
Video: Finding All Subnet IDs with Less Than 8 Subnet Bits	Watch Video Lesson 11			

Video: Finding All Subnet IDs with More Than 8 Subnet Bits	Watch Video Lesson 12			
19) Subnet Design	Do Exam Prep Tasks			
G Practice for Chapter 19: Subnet Design	Solve Practice Problems			
20) Variable-Length Subnet Masks	Read Foundation Topics			
20) Variable-Length Subnet Masks	Do Exam Prep Tasks			
H Practice for Chapter 20: Variable-Length Subnet Masks	Solve Practice Problems			
21) Route Summarization	Read Foundation Topics			
21) Route Summarization	Do Exam Prep Tasks			
I: Practice for Chapter 21: Route Summarization	Solve Practice Problems			
Part V Review	Do Part Review Activities			
22) Basic IPv4 Access Control Lists	Read Foundation Topics			
22) Basic IPv4 Access Control Lists	Do Exam Prep Tasks			
J: Practice for Chapter 22: Basic IPv4 Access Control Lists	Solve Practice Problems			
23) Advanced IPv4 ACLs and Device Security	Read Foundation Topics			
23) Advanced IPv4 ACLs and Device Security	Do Exam Prep Tasks			
24) Network Address Translation	Read Foundation Topics			
24) Network Address Translation	Do Exam Prep Tasks			
Part VI Review	Do Part Review Activities			
25) Fundamentals of IP Version 6	Read Foundation Topics			
25) Fundamentals of IP Version 6	Do Exam Prep Tasks			
K: Practice for Chapter 25: Fundamentals of IP Version 6	Solve Practice Problems			
26) IPv6 Addressing and Subnetting	Read Foundation Topics			
26) IPv6 Addressing and Subnetting	Do Exam Prep Tasks			
27) Implementing IPv6 Addressing on Routers	Read Foundation Topics			
27) Implementing IPv6 Addressing on Routers	Do Exam Prep Tasks			
L: Practice for Chapter 27: Implementing IPv6 Addressing on Routers	Solve Practice Problems			
28) Implementing IPv6 Addressing on Hosts	Read Foundation Topics			
28) Implementing IPv6 Addressing on Hosts	Do Exam Prep Tasks			
29) Implementing IPv6 Routing	Read Foundation Topics			
29) Implementing IPv6 Routing	Do Exam Prep Tasks			
Part VII Review	Do Part Review Activities			
30) Final Review	Practice Subnetting for Speed			
30) Final Review	Take Practice Exams			
30) Final Review	Review Questions			
30) Final Review	Practice CLI Skills			

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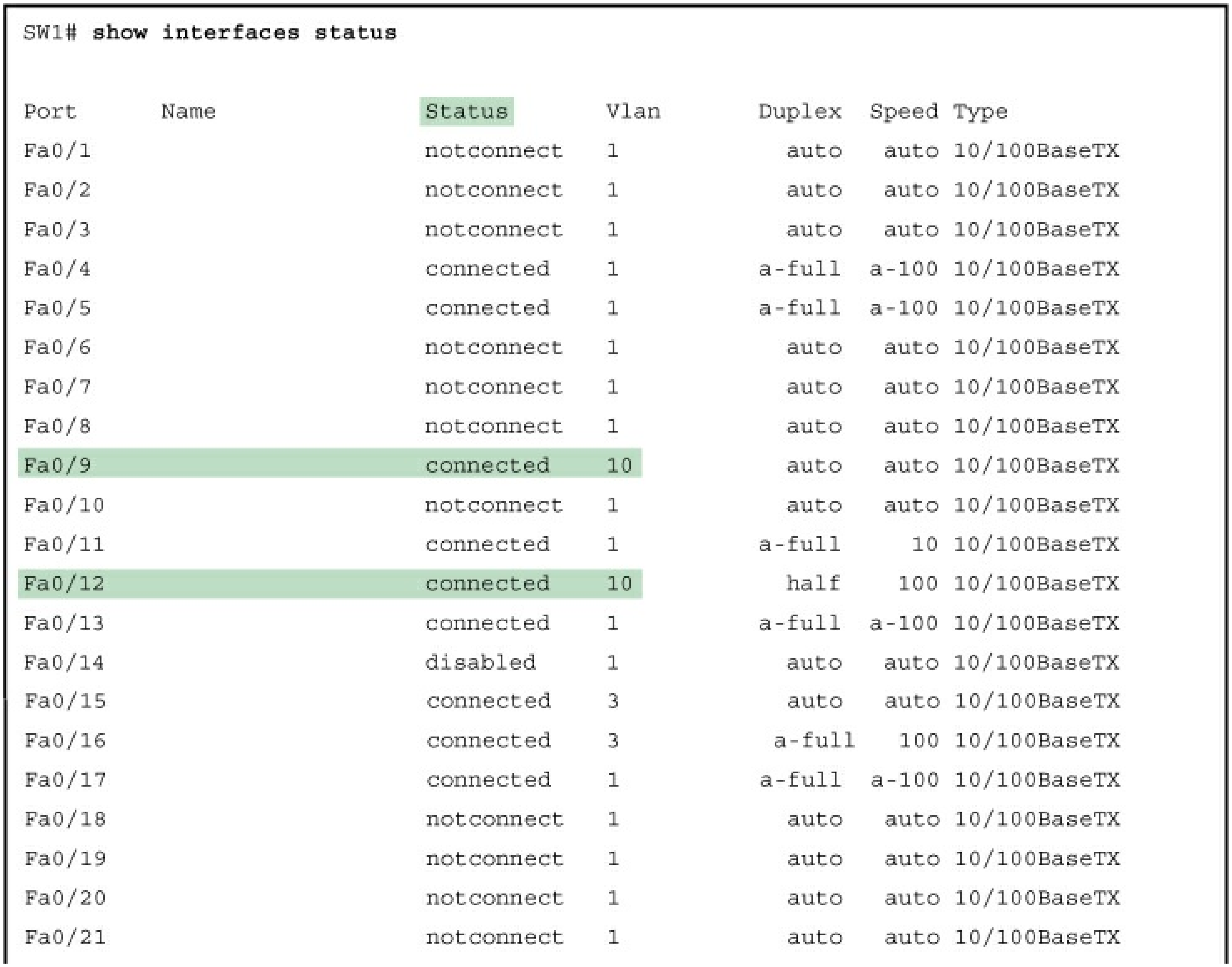
```
SW1# show interfaces f0/11 status

Port      Name               Status       Vlan       Duplex  Speed Type
Fa0/11                       connected    3          a-full    100 10/100BaseTX
```

```
SW1# show mac address-table dynamic
          Mac Address Table
-------------------------------------------

Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
  10    0200.1111.1111    DYNAMIC     Fa0/9
  10    0200.2222.2222    DYNAMIC     Fa0/12
  10    0200.5555.5555    DYNAMIC     Gi0/1
```

```
SW2# show mac address-table dynamic
          Mac Address Table
-------------------------------------------

Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
  10    0200.1111.1111    DYNAMIC     Gi0/2
  10    0200.2222.2222    DYNAMIC     Gi0/2
  10    0200.5555.5555    DYNAMIC     Fa0/13
```



```
SW1# show interfaces status

Port      Name               Status       Vlan       Duplex  Speed Type
Fa0/1                        notconnect   1            auto   auto 10/100BaseTX
Fa0/2                        notconnect   1            auto   auto 10/100BaseTX
Fa0/3                        notconnect   1            auto   auto 10/100BaseTX
Fa0/4                        connected    1          a-full  a-100 10/100BaseTX
Fa0/5                        connected    1          a-full  a-100 10/100BaseTX
Fa0/6                        notconnect   1            auto   auto 10/100BaseTX
Fa0/7                        notconnect   1            auto   auto 10/100BaseTX
Fa0/8                        notconnect   1            auto   auto 10/100BaseTX
Fa0/9                        connected    10           auto   auto 10/100BaseTX
Fa0/10                       notconnect   1            auto   auto 10/100BaseTX
Fa0/11                       connected    1          a-full     10 10/100BaseTX
Fa0/12                       connected    10           half    100 10/100BaseTX
Fa0/13                       connected    1          a-full  a-100 10/100BaseTX
Fa0/14                       disabled     1            auto   auto 10/100BaseTX
Fa0/15                       connected    3            auto   auto 10/100BaseTX
Fa0/16                       connected    3           a-full   100 10/100BaseTX
Fa0/17                       connected    1          a-full  a-100 10/100BaseTX
Fa0/18                       notconnect   1            auto   auto 10/100BaseTX
Fa0/19                       notconnect   1            auto   auto 10/100BaseTX
Fa0/20                       notconnect   1            auto   auto 10/100BaseTX
Fa0/21                       notconnect   1            auto   auto 10/100BaseTX
```

```
Fa0/22                       notconnect   1            auto   auto 10/100BaseTX
Fa0/23                       notconnect   1            auto   auto 10/100BaseTX
Fa0/24                       notconnect   1            auto   auto 10/100BaseTX
Gi0/1                        connected    trunk        full   1000 10/100/1000BaseTX
Gi0/2                        notconnect   1            auto   auto 10/100/1000BaseTX

SW1# show vlan brief

VLAN Name                             Status    Ports
---- -------------------------------- --------- -------------------------------
1    default                          active    Fa0/1, Fa0/2, Fa0/3, Fa0/4
                                                Fa0/5, Fa0/6, Fa0/7, Fa0/8
                                                Fa0/9, Fa0/10, Fa0/11, Fa0/12
                                                Fa0/17, Fa0/18, Fa0/19, Fa0/20
                                                Fa0/21, Fa0/22, Fa0/23, Fa0/24
                                                Gi0/2
3    VLAN0003                         active    Fa0/15, Fa0/16
10   WO-example                       active    Fa0/9, Fa0/12
1002 fddi-default                     act/unsup
1003 token-ring-default               act/unsup
1004 fddinet-default                  act/unsup
1005 trnet-default                    act/unsup
```

```
SW1# show interfaces trunk

Port        Mode         Encapsulation  Status        Native vlan
Gi0/1       desirable    802.1q         trunking      1

Port        Vlans allowed on trunk
Gi0/1       1-4094

Port        Vlans allowed and active in management domain
Gi0/1       1, 3, 10

Port        Vlans in spanning tree forwarding state and not pruned
Gi0/1       1, 3, 10
```

```
Bridge ID  Priority    32771  (priority 32768 sys-id-ext 3)
           Address     0019.e86a.6f80
```

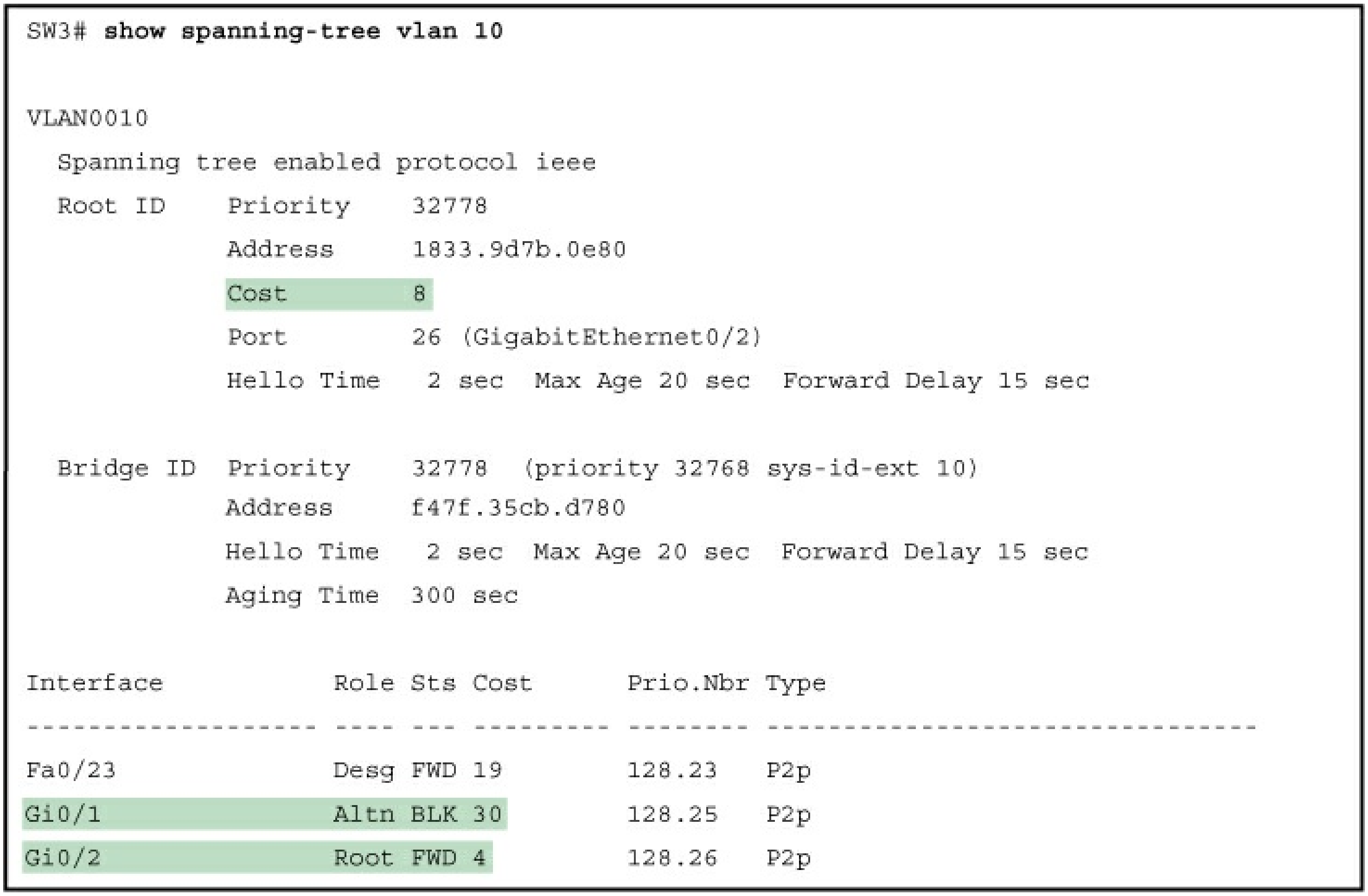
```
SW3# show interfaces status
Port      Name      Status       Vlan      Duplex     Speed      Type
Fa0/13              connected    1         a-half     a-100      10/100BaseTX
Gi0/1               connected    1         a-full     a-1000     1000BaseTX
```

```
SW1# show spanning-tree vlan 10

VLAN0010
  Spanning tree enabled protocol ieee
  Root ID    Priority    32778
             Address     1833.9d7b.0e80
             This bridge is the root
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID  Priority    32778  (priority 32768 sys-id-ext 10)
             Address     1833.9d7b.0e80
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec
             Aging Time  300 sec

Interface           Role Sts Cost      Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------------
Fa0/11              Desg FWD 19        128.11   P2p Edge
Gi0/1               Desg FWD 4         128.25   P2p
Gi0/2               Desg FWD 4         128.26   P2p
```

```
SW2# show spanning-tree vlan 10

VLAN0010
  Spanning tree enabled protocol ieee
  Root ID    Priority    32778
             Address     1833.9d7b.0e80
             Cost        4
             Port        26 (GigabitEthernet0/2)
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID  Priority    32778  (priority 32768 sys-id-ext 10)
             Address     1833.9d7b.1380
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec
             Aging Time  300 sec

Interface           Role Sts Cost      Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------------
Fa0/12              Desg FWD 19        128.12   P2p
Gi0/1               Desg FWD 4         128.25   P2p
Gi0/2               Root FWD 4         128.26   P2p
```

```
SW2# show spanning-tree root

                                        Root    Hello Max Fwd
Vlan                   Root ID          Cost    Time  Age Dly  Root Port
---------------- -------------------- --------- ----- --- ---  ------------
VLAN0001         32769 1833.9d5d.c900        23    2   20  15  Gi0/1
VLAN0010         32778 1833.9d7b.0e80         4    2   20  15  Gi0/2
VLAN0020         32788 1833.9d7b.0e80         4    2   20  15  Gi0/2
VLAN0030         32798 1833.9d7b.0e80         4    2   20  15  Gi0/2
VLAN0040         32808 1833.9d7b.0e80         4    2   20  15  Gi0/2

SW2# show spanning-tree vlan 10 bridge

                                                   Hello  Max  Fwd
Vlan                         Bridge ID              Time  Age  Dly  Protocol
---------------- --------------------------------- -----  ---  ---  --------
VLAN0010         32778 (32768,  10) 1833.9d7b.1380    2    20   15  ieee
```

```
SW3# debug spanning-tree events
Spanning Tree event debugging is on
SW3# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
SW3(config)# interface gigabitethernet0/1
SW3(config-if)# spanning-tree vlan 10 cost 30
SW3(config-if)# ^Z
SW3#
*Mar 11 06:28:00.860: STP: VLAN0010 new root port Gi0/2, cost 8
*Mar 11 06:28:00.860: STP: VLAN0010 Gi0/2 -> listening
*Mar 11 06:28:00.860: STP: VLAN0010 sent Topology Change Notice on Gi0/2
*Mar 11 06:28:00.860: STP[10]: Generating TC trap for port GigabitEthernet0/1
*Mar 11 06:28:00.860: STP: VLAN0010 Gi0/1 -> blocking
*Mar 11 06:28:15.867: STP: VLAN0010 Gi0/2 -> learning
*Mar 11 06:28:30.874: STP[10]: Generating TC trap for port GigabitEthernet0/2
*Mar 11 06:28:30.874: STP: VLAN0010 sent Topology Change Notice on Gi0/2
*Mar 11 06:28:30.874: STP: VLAN0010 Gi0/2 -> forwarding
```



```
SW3# show spanning-tree vlan 10

VLAN0010
  Spanning tree enabled protocol ieee
  Root ID    Priority    32778
             Address     1833.9d7b.0e80
             Cost        8
             Port        26 (GigabitEthernet0/2)
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID  Priority    32778  (priority 32768 sys-id-ext 10)
             Address     f47f.35cb.d780
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec
             Aging Time  300 sec

Interface           Role Sts Cost      Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------------
Fa0/23              Desg FWD 19        128.23   P2p
Gi0/1               Altn BLK 30        128.25   P2p
Gi0/2               Root FWD 4         128.26   P2p
```

```
! First, on SW2:
SW2# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
SW2(config)# spanning-tree vlan 10 root primary
SW2(config)# ^Z
```

```
! Next, SW1 is configured to back-up SW1
SW1# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
SW1(config)# spanning-tree vlan 10 root secondary
SW1(config)# ^Z
SW1#

! The next command shows the local switch's BID (SW1)
SW1# show spanning-tree vlan 10 bridge

                                                   Hello  Max  Fwd
Vlan                             Bridge ID          Time  Age  Dly  Protocol
---------------- --------------------------------- -----  ---  ---  --------
VLAN0010          28682 (28672,  10) 1833.9d7b.0e80    2    20   15  ieee

! The next command shows the root's BID (SW2)
SW1# show spanning-tree vlan 10 root

                                        Root    Hello Max Fwd
Vlan                       Root ID          Cost    Time  Age Dly  Root Port
---------------- -------------------- --------- ----- --- ---  ------------
VLAN0010          24586 1833.9d7b.1380         4    2   20  15  Gi0/1
```

```
SW3# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
SW3(config)# interface fastEthernet 0/4
SW3(config-if)# spanning-tree portfast
%Warning: portfast should only be enabled on ports connected to a single
 host. Connecting hubs, concentrators, switches, bridges, etc... to this
 interface  when portfast is enabled, can cause temporary bridging loops.
 Use with CAUTION

%Portfast has been configured on FastEthernet0/4 but will only
 have effect when the interface is in a non-trunking mode.

SW3(config-if)# spanning-tree bpduguard ?
  disable  Disable BPDU guard for this interface
  enable   Enable BPDU guard for this interface

SW3(config-if)# spanning-tree bpduguard enable
SW3(config-if)# ^Z
SW3#
*Mar  1 07:53:47.808: %SYS-5-CONFIG_I: Configured from console by console
SW3# show running-config interface f0/4
Building configuration...

Current configuration : 138 bytes
!
interface FastEthernet0/4
 switchport access vlan 104
 spanning-tree portfast
 spanning-tree bpduguard enable
end

SW3# show spanning-tree interface fastethernet0/4 portfast
VLAN0104            enabled
```

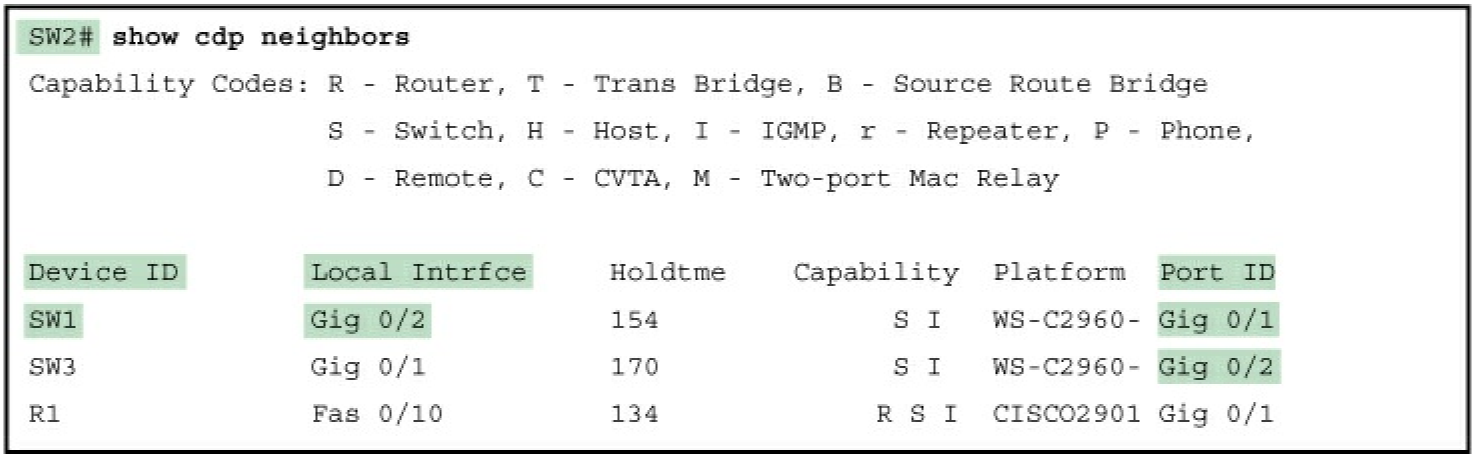
```
SW1# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
SW1(config)# interface fa 0/14
SW1(config-if)# channel-group 1 mode on
SW1(config)# interface fa 0/15
SW1(config-if)# channel-group 1 mode on
SW1(config-if)# ^Z

SW1# show spanning-tree vlan 3

VLAN0003
  Spanning tree enabled protocol ieee
  Root ID    Priority    28675
             Address     0019.e859.5380
             Cost        12
             Port        72 (Port-channel1)
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID  Priority    28675  (priority 28672 sys-id-ext 3)
             Address     0019.e86a.6f80
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec
             Aging Time 300

Interface        Role Sts Cost      Prio.Nbr Type
---------------- ---- --- --------- -------- --------------------------------
Po1              Root FWD 12        128.64   P2p Peer(STP)
```

```
SW1# show etherchannel 1 summary
Flags:  D - down        P - bundled in port-channel
        I - stand-alone s - suspended
        H - Hot-standby (LACP only)
        R - Layer3      S - Layer2
        U - in use      f - failed to allocate aggregator

        M - not in use, minimum links not met
        u - unsuitable for bundling
        w - waiting to be aggregated
        d - default port


Number of channel-groups in use: 1
Number of aggregators:           1

Group  Port-channel  Protocol    Ports
------+-------------+-----------+-----------------------------------------------
1      Po1(SU)          -        Fa0/14(P)   Fa0/15(P)
```

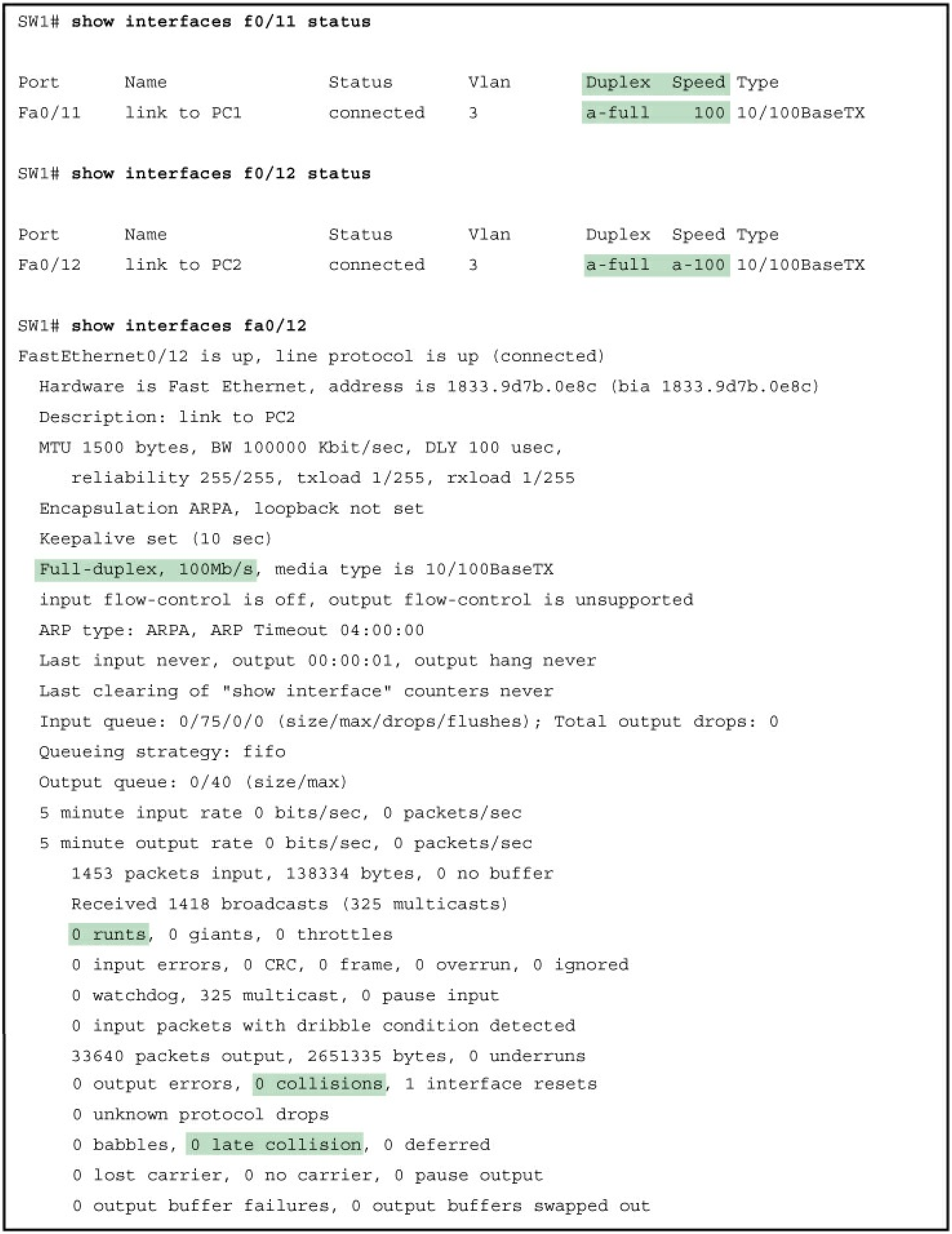
```
SW2# show spanning-tree vlan 20 root

                                        Root    Hello Max Fwd
Vlan                   Root ID          Cost    Time  Age Dly  Root Port
---------------- -------------------- --------- ----- --- ---  ------------
VLAN0020         32788 1833.9d7b.0e80         4    2   20  15  Gi0/2

SW2# show spanning-tree vlan 20

VLAN0020
  Spanning tree enabled protocol ieee
  Root ID    Priority    32788
             Address     1833.9d7b.0e80
             Cost        4
             Port        26 (GigabitEthernet0/2)
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID  Priority    32788  (priority 32768 sys-id-ext 20)
             Address     1833.9d7b.1380
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec
             Aging Time  15  sec

Interface           Role Sts Cost      Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------------
Gi0/1               Desg FWD 4         128.25   P2p
Gi0/2               Root FWD 4         128.26   P2p
```

```
SW1# show etherchannel summary
Flags:  D - down        P - bundled in port-channel
        I - stand-alone s - suspended
        H - Hot-standby (LACP only)
        R - Layer3      S - Layer2
        U - in use      f - failed to allocate aggregator

        M - not in use, minimum links not met
        u - unsuitable for bundling
        w - waiting to be aggregated
        d - default port


Number of channel-groups in use: 1
Number of aggregators:           1

Group  Port-channel  Protocol    Ports
------+-------------+-----------+-----------------------------------------------
1      Po1(SD)         PAgP      Fa0/14(I)   Fa0/15(I)

SW1# show interfaces status | include Po|14|15
Port      Name               Status       Vlan       Duplex  Speed Type
Fa0/14                       connected    301        a-full  a-100 10/100BaseTX
Fa0/15                       connected    301        a-full  a-100 10/100BaseTX
Po1                          notconnect   unassigned   auto   auto
```

```
*Mar  1 23:18:56.132: %PM-4-ERR_DISABLE: channel-misconfig (STP) error detected on
Po1, putting Fa0/14 in err-disable state
*Mar  1 23:18:56.132: %PM-4-ERR_DISABLE: channel-misconfig (STP) error detected on
Po1, putting Fa0/15 in err-disable state
*Mar  1 23:18:56.132: %PM-4-ERR_DISABLE: channel-misconfig (STP) error detected on
Po1, putting Po1 in err-disable state
*Mar  1 23:18:58.120: %LINK-3-UPDOWN: Interface FastEthernet0/14, changed state to
down
*Mar  1 23:18:58.137: %LINK-3-UPDOWN: Interface Port-channel1, changed state to down
*Mar  1 23:18:58.137: %LINK-3-UPDOWN: Interface FastEthernet0/15, changed state to
down

SW1# show etherchannel summary
Flags:  D - down         P - bundled in port-channel
        I - stand-alone s - suspended
        H - Hot-standby (LACP only)
        R - Layer3      S - Layer2
        U - in use      f - failed to allocate aggregator

        M - not in use, minimum links not met
        u - unsuitable for bundling
        w - waiting to be aggregated
        d - default port


Number of channel-groups in use: 1
Number of aggregators:           1

Group  Port-channel  Protocol    Ports
------+-------------+-----------+-----------------------------------------
1      Po1(SD)          -        Fa0/14(D)   Fa0/15(D)
```



```
SW2# show cdp neighbors
Capability Codes: R - Router, T - Trans Bridge, B - Source Route Bridge
                  S - Switch, H - Host, I - IGMP, r - Repeater, P - Phone,
                  D - Remote, C - CVTA, M - Two-port Mac Relay

Device ID        Local Intrfce     Holdtme    Capability  Platform  Port ID
SW1              Gig 0/2           154              S I   WS-C2960- Gig 0/1
SW3              Gig 0/1           170              S I   WS-C2960- Gig 0/2
R1               Fas 0/10          134            R S I   CISCO2901 Gig 0/1
```



```
SW1# show interfaces f0/11 status

Port      Name               Status       Vlan       Duplex  Speed Type
Fa0/11    link to PC1        connected    3          a-full    100 10/100BaseTX

SW1# show interfaces f0/12 status

Port      Name               Status       Vlan       Duplex  Speed Type
Fa0/12    link to PC2        connected    3          a-full  a-100 10/100BaseTX

SW1# show interfaces fa0/12
FastEthernet0/12 is up, line protocol is up (connected)
  Hardware is Fast Ethernet, address is 1833.9d7b.0e8c (bia 1833.9d7b.0e8c)
  Description: link to PC2
  MTU 1500 bytes, BW 100000 Kbit/sec, DLY 100 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation ARPA, loopback not set
  Keepalive set (10 sec)
  Full-duplex, 100Mb/s, media type is 10/100BaseTX
  input flow-control is off, output flow-control is unsupported
  ARP type: ARPA, ARP Timeout 04:00:00
  Last input never, output 00:00:01, output hang never
  Last clearing of "show interface" counters never
  Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
  Queueing strategy: fifo
  Output queue: 0/40 (size/max)
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
     1453 packets input, 138334 bytes, 0 no buffer
     Received 1418 broadcasts (325 multicasts)
     0 runts, 0 giants, 0 throttles
     0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored
     0 watchdog, 325 multicast, 0 pause input
     0 input packets with dribble condition detected
     33640 packets output, 2651335 bytes, 0 underruns
     0 output errors, 0 collisions, 1 interface resets
     0 unknown protocol drops
     0 babbles, 0 late collision, 0 deferred
     0 lost carrier, 0 no carrier, 0 pause output
     0 output buffer failures, 0 output buffers swapped out
```

```
SW1# show interfaces gi0/1 status

Port      Name               Status       Vlan       Duplex  Speed Type
Gi0/1     Link to SW2        connected    trunk      a-half  a-100 10/100/1000BaseTX
```

```
! The first command lists all interfaces on which port security has been enabled,
! and the violation mode, under the heading "Security Action".
SW1# show port-security
Secure Port  MaxSecureAddr  CurrentAddr  SecurityViolation  Security Action
                (Count)       (Count)          (Count)
---------------------------------------------------------------------------
    Fa0/13             1            1                  1          Shutdown
---------------------------------------------------------------------------
Total Addresses in System (excluding one mac per port)     : 0
Max Addresses limit in System (excluding one mac per port) : 8192

!
! The next command shows the err-disabled state, implying a security violation.
SW1# show interfaces Fa0/13 status

Port      Name               Status       Vlan       Duplex  Speed Type
Fa0/13                       err-disabled 1            auto   auto 10/100BaseTX
!
! The next command's output has shading for several of the most important facts.
SW1# show port-security interface Fa0/13
Port Security              : Enabled
Port Status                : Secure-shutdown
Violation Mode             : Shutdown
Aging Time                 : 0 mins
Aging Type                 : Absolute
SecureStatic Address Aging : Disabled
Maximum MAC Addresses      : 1
Total MAC Addresses        : 1
Configured MAC Addresses   : 1
Sticky MAC Addresses       : 0
Last Source Address:Vlan   : 0200.3333.3333:2
Security Violation Count   : 1
```

```
SW1# show running-config
! Lines omitted for brevity
interface FastEthernet0/13
 switchport mode access
 switchport port-security
 switchport port-security mac-address 0200.1111.1111
 switchport port-security violation protect
! Lines omitted for brevity

SW1# show port-security interface Fa0/13
Port Security              : Enabled
Port Status                : Secure-up
Violation Mode             : Protect
Aging Time                 : 0 mins
Aging Type                 : Absolute
SecureStatic Address Aging : Disabled
Maximum MAC Addresses      : 1
Total MAC Addresses        : 1
Configured MAC Addresses   : 1
Sticky MAC Addresses       : 0
Last Source Address:Vlan   : 0200.3333.3333:1
Security Violation Count   : 0
```

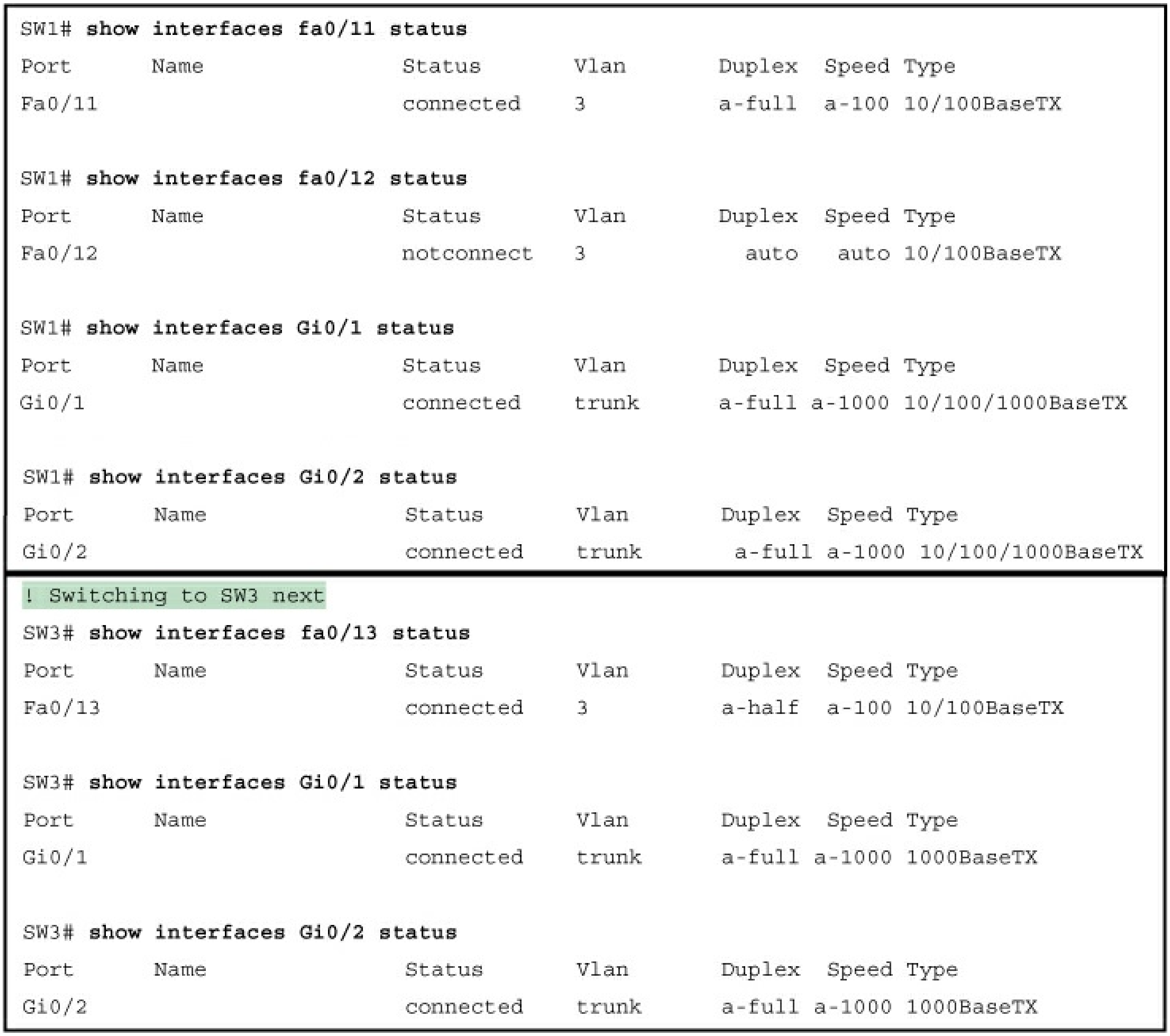
```
SW1# show interfaces trunk

Port        Mode         Encapsulation  Status        Native vlan
Gi0/1       desirable    802.1q         trunking      1

Port        Vlans allowed on trunk
Gi0/1       1-2,4-4094

Port        Vlans allowed and active in management domain
Gi0/1       1,4

Port        Vlans in spanning tree forwarding state and not pruned
Gi0/1       1,4
```

```
SW1# show cdp neighbors
Capability Codes: R - Router, T - Trans Bridge, B - Source Route Bridge
                  S - Switch, H - Host, I - IGMP, r - Repeater, P - Phone,
                  D - Remote, C - CVTA, M - Two-port Mac Relay

Device ID        Local Intrfce     Holdtme    Capability  Platform  Port ID
SW2              Gig 0/1           170              S I   WS-C2960- Gig 0/2
SW3              Gig 0/2           167              S I   WS-C2960- Gig 0/1
```

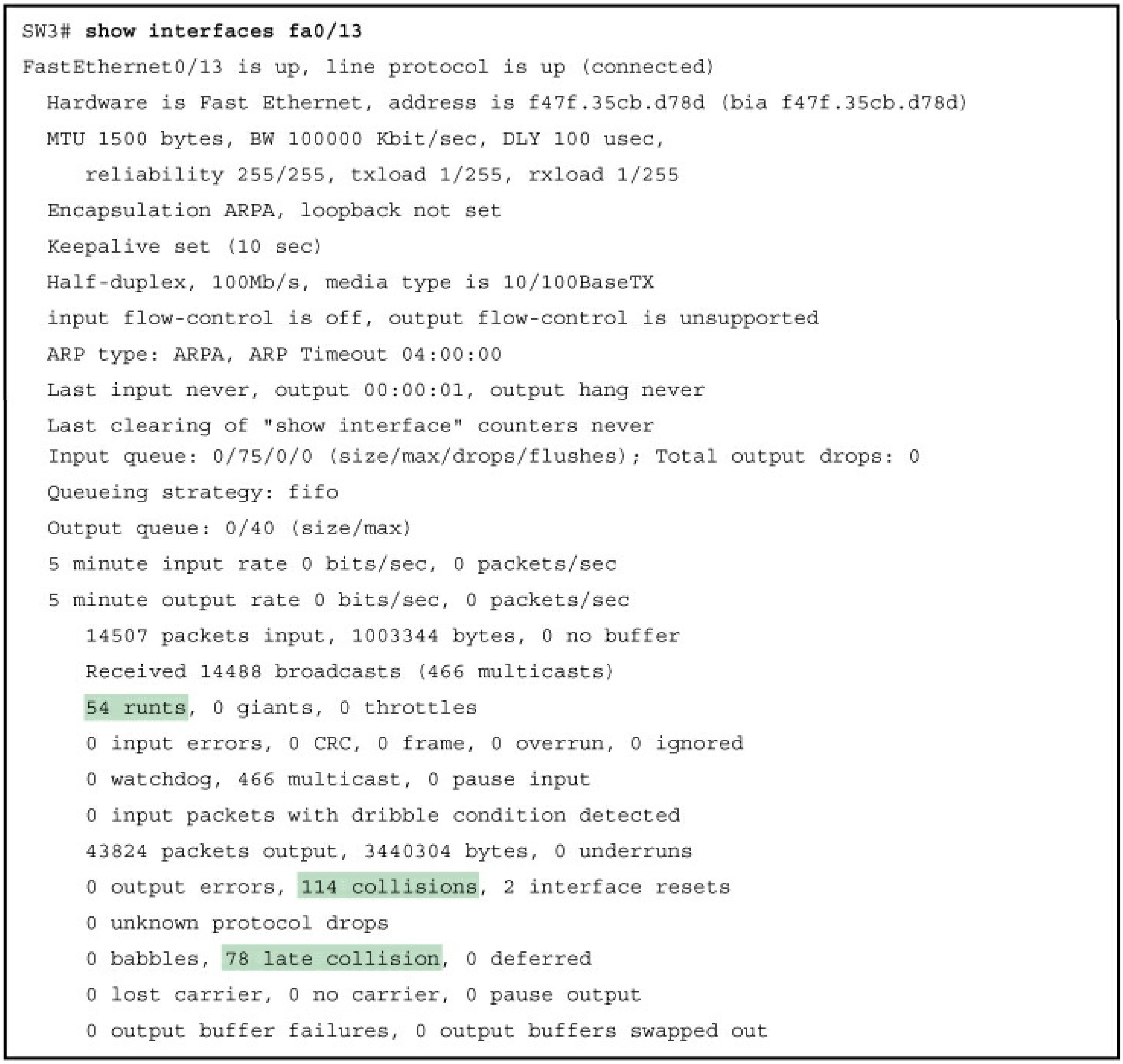
```
! SW2 commands next
SW2# show cdp neighbors
Capability Codes: R - Router, T - Trans Bridge, B - Source Route Bridge
                  S - Switch, H - Host, I - IGMP, r - Repeater, P - Phone,
                  D - Remote, C - CVTA, M - Two-port Mac Relay

Device ID        Local Intrfce     Holdtme    Capability  Platform  Port ID
SW1              Gig 0/2           146              S I   WS-C2960- Gig 0/1
SW3              Gig 0/1           162              S I   WS-C2960- Gig 0/2
R1               Fas 0/9           139            R S I   CISCO2901 Gig 0/1

SW2# show cdp entry R1
-------------------------
Device ID: R1
Entry address(es):
  IP address: 2.2.2.9
```

```
Platform: Cisco CISCO2901/K9,  Capabilities: Router Switch IGMP
Interface: FastEthernet0/9,  Port ID (outgoing port): GigabitEthernet0/1
Holdtime : 148 sec

Version :
Cisco IOS Software, C2900 Software (C2900-UNIVERSALK9-M), Version 15.2(4)M1, RELEASE
SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2012 by Cisco Systems, Inc.
Compiled Thu 26-Jul-12 20:54 by prod_rel_team

advertisement version: 2
VTP Management Domain: ''
Duplex: full
Management address(es):
```

```
! SW3 command next
SW3# show cdp neighbors
Capability Codes: R - Router, T - Trans Bridge, B - Source Route Bridge
                  S - Switch, H - Host, I - IGMP, r - Repeater, P - Phone,
                  D - Remote, C - CVTA, M - Two-port Mac Relay

Device ID        Local Intrfce     Holdtme    Capability  Platform  Port ID
SW1              Gig 0/1           167              S I   WS-C2960- Gig 0/2
SW2              Gig 0/2           176              S I   WS-C2960- Gig 0/1
```



```
SW1# show interfaces fa0/11 status
Port      Name               Status       Vlan       Duplex  Speed Type
Fa0/11                       connected    3          a-full  a-100 10/100BaseTX

SW1# show interfaces fa0/12 status
Port      Name               Status       Vlan       Duplex  Speed Type
Fa0/12                       notconnect   3            auto   auto 10/100BaseTX

SW1# show interfaces Gi0/1 status
Port      Name               Status       Vlan       Duplex  Speed Type
Gi0/1                        connected    trunk      a-full a-1000 10/100/1000BaseTX

SW1# show interfaces Gi0/2 status
Port      Name               Status       Vlan       Duplex  Speed Type
Gi0/2                        connected    trunk       a-full a-1000 10/100/1000BaseTX
! Switching to SW3 next
SW3# show interfaces fa0/13 status
Port      Name               Status       Vlan       Duplex  Speed Type
Fa0/13                       connected    3          a-half  a-100 10/100BaseTX

SW3# show interfaces Gi0/1 status
Port      Name               Status       Vlan       Duplex  Speed Type
Gi0/1                        connected    trunk      a-full a-1000 1000BaseTX

SW3# show interfaces Gi0/2 status
Port      Name               Status       Vlan       Duplex  Speed Type
Gi0/2                        connected    trunk      a-full a-1000 1000BaseTX
```



```
SW3# show interfaces fa0/13
FastEthernet0/13 is up, line protocol is up (connected)
  Hardware is Fast Ethernet, address is f47f.35cb.d78d (bia f47f.35cb.d78d)
  MTU 1500 bytes, BW 100000 Kbit/sec, DLY 100 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation ARPA, loopback not set
  Keepalive set (10 sec)
  Half-duplex, 100Mb/s, media type is 10/100BaseTX
  input flow-control is off, output flow-control is unsupported
  ARP type: ARPA, ARP Timeout 04:00:00
  Last input never, output 00:00:01, output hang never
  Last clearing of "show interface" counters never
  Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
  Queueing strategy: fifo
  Output queue: 0/40 (size/max)
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
     14507 packets input, 1003344 bytes, 0 no buffer
     Received 14488 broadcasts (466 multicasts)
     54 runts, 0 giants, 0 throttles
     0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored
     0 watchdog, 466 multicast, 0 pause input
     0 input packets with dribble condition detected
     43824 packets output, 3440304 bytes, 0 underruns
     0 output errors, 114 collisions, 2 interface resets
     0 unknown protocol drops
     0 babbles, 78 late collision, 0 deferred
     0 lost carrier, 0 no carrier, 0 pause output
     0 output buffer failures, 0 output buffers swapped out
```

```
SW1# show port-security
Secure Port  MaxSecureAddr  CurrentAddr  SecurityViolation  Security Action
                (Count)       (Count)          (Count)
---------------------------------------------------------------------------
     Fa0/11              1            1                 97         Restrict
---------------------------------------------------------------------------
Total Addresses in System (excluding one mac per port)     : 0
Max Addresses limit in System (excluding one mac per port) : 4096
```

```
! On SW2 below, no interfaces have port security enabled.
SW2# show port-security
Secure Port  MaxSecureAddr  CurrentAddr  SecurityViolation  Security Action
                (Count)       (Count)          (Count)
---------------------------------------------------------------------------
---------------------------------------------------------------------------
Total Addresses in System (excluding one mac per port)     : 0
Max Addresses limit in System (excluding one mac per port) : 8192
```

```
SW1# show port-security interface fa0/11
Port Security              : Enabled
Port Status                : Secure-up
Violation Mode             : Restrict
Aging Time                 : 0 mins
Aging Type                 : Absolute
SecureStatic Address Aging : Disabled
Maximum MAC Addresses      : 1
Total MAC Addresses        : 1
Configured MAC Addresses   : 1
Sticky MAC Addresses       : 0
Last Source Address:Vlan   : 0200.1111.1111:3
Security Violation Count   : 97
!
! Next, the configuration shows that the configured MAC address does not
! match PC1's MAC address.
SW1# show running-config interface fa0/11

interface FastEthernet0/11
 switchport access vlan 3
 switchport mode access
 switchport port-security
 switchport port-security violation restrict
 switchport port-security mac-address 0200.3333.3333
!
! The following log message also points to a port security issue.
01:46:58: %PORT_SECURITY-2-PSECURE_VIOLATION: Security violation occurred, caused by
MAC address 0200.1111.1111 on port FastEthernet0/11.
```

```
SW1# show interfaces fa0/11 status

Port      Name               Status       Vlan       Duplex  Speed Type
Fa0/11                       connected    3          a-full  a-100 10/100BaseTX
SW1# show interfaces fa0/12 status

Port      Name               Status       Vlan       Duplex  Speed Type
Fa0/12                       notconnect   3            auto   auto 10/100BaseTX
```

```
! SW2 next
SW2# show interfaces status
! lines omitted for brevity
Fa0/9                        connected    1          a-full  a-100 10/100BaseTX
Fa0/10                       notconnect   3            auto   auto 10/100BaseTX
```

```
! SW3 next
SW3# show interfaces fa0/13 status

Port      Name               Status       Vlan       Duplex  Speed Type
Fa0/13                       connected    3            full  a-100 10/100BaseTX
```

```
SW1# show vlan id 3

VLAN Name                             Status    Ports
---- -------------------------------- --------- -------------------------------
3    book-vlan3                       active    Fa0/11, Fa0/12, Gi0/1, Gi0/2
! lines omitted for brevity
```

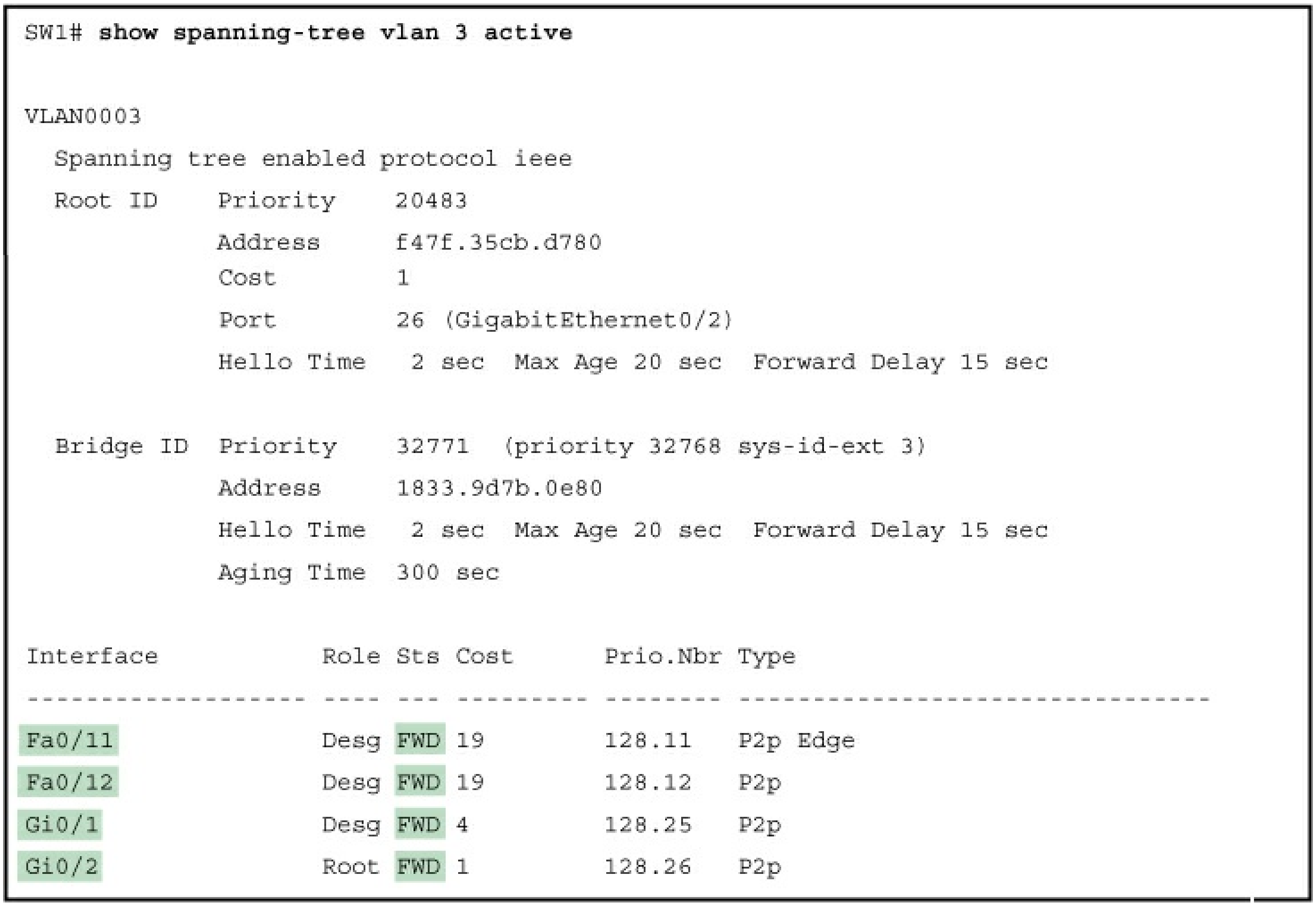
```
! SW2 next
SW2# show vlan brief

VLAN Name                             Status    Ports
---- -------------------------------- --------- -------------------------------
1    default                          active    Fa0/1, Fa0/2, Fa0/3, Fa0/4
                                                Fa0/5, Fa0/6, Fa0/7, Fa0/8
                                                Fa0/11, Fa0/12, Fa0/13, Fa0/14
                                                Fa0/15, Fa0/16, Fa0/17, Fa0/18
                                                Fa0/19, Fa0/20, Fa0/21, Fa0/22
                                                Fa0/23, Fa0/24
3    VLAN0003                         active    Fa0/9, Fa0/10
! lines omitted for brevity
```

```
! SW3 next
SW3# show vlan brief

VLAN Name                             Status    Ports
---- -------------------------------- --------- -------------------------------
1    default                          active    Fa0/1, Fa0/2, Fa0/3, Fa0/4
                                                Fa0/5, Fa0/6, Fa0/7, Fa0/8
                                                Fa0/9, Fa0/10, Fa0/11, Fa0/12
                                                Fa0/14, Fa0/15, Fa0/16, Fa0/17
                                                Fa0/18, Fa0/19, Fa0/20, Fa0/21
                                                Fa0/22, Fa0/23, Fa0/24
3    book-vlan3                       active    Fa0/13
! lines omitted for brevity
```

```
SW1# show interfaces trunk

Port        Mode         Encapsulation  Status        Native vlan
Gi0/1       desirable    802.1q         trunking      1
Gi0/2       desirable    802.1q         trunking      1

Port        Vlans allowed on trunk
Gi0/1       1-4094
Gi0/2       1-4094

Port        Vlans allowed and active in management domain
Gi0/1       1,3
Gi0/2       1,3

Port        Vlans in spanning tree forwarding state and not pruned
Gi0/1       3
Gi0/2       1,3
! SW2 next
SW2# show interfaces trunk

Port        Mode         Encapsulation  Status        Native vlan
Gi0/1       auto         802.1q         trunking      1
Gi0/2       auto         802.1q         trunking      1
```

```
Port        Vlans allowed on trunk
Gi0/1       1-4094
Gi0/2       1-4094

Port        Vlans allowed and active in management domain
Gi0/1       1,3
Gi0/2       1,3

Port        Vlans in spanning tree forwarding state and not pruned
Gi0/1       1,3
Gi0/2       1
```

```
! SW3 next
SW3# show interfaces trunk


Port        Mode         Encapsulation  Status        Native vlan
Gi0/1       auto         802.1q         trunking      1
Gi0/2       desirable    802.1q         trunking      1

Port      Vlans allowed on trunk
Gi0/1       1-4094
Gi0/2       1-4094

Port        Vlans allowed and active in management domain
Gi0/1       1,3
Gi0/2       1,3

Port        Vlans in spanning tree forwarding state and not pruned
Gi0/1       1,3
Gi0/2       1,3
```



```
SW1# show spanning-tree vlan 3 active

VLAN0003
  Spanning tree enabled protocol ieee
  Root ID    Priority    20483
             Address     f47f.35cb.d780
             Cost        1
             Port        26 (GigabitEthernet0/2)
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID  Priority    32771  (priority 32768 sys-id-ext 3)
             Address     1833.9d7b.0e80
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec
             Aging Time  300 sec

Interface           Role Sts Cost      Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------------
Fa0/11              Desg FWD 19        128.11   P2p Edge
Fa0/12              Desg FWD 19        128.12   P2p
Gi0/1               Desg FWD 4         128.25   P2p
Gi0/2               Root FWD 1         128.26   P2p
```

```
SW2# show spanning-tree vlan 3

VLAN0003
  Spanning tree enabled protocol ieee
  Root ID    Priority    20483
             Address     f47f.35cb.d780
             Cost        4
             Port        25 (GigabitEthernet0/1)
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID  Priority    32771  (priority 32768 sys-id-ext 3)
             Address     1833.9d7b.1380
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec
             Aging Time  300 sec
Interface           Role Sts Cost      Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------------
Fa0/9               Desg FWD 19        128.9    P2p
Gi0/1               Root FWD 4         128.25   P2p
Gi0/2               Altn BLK 4         128.26   P2p
```

```
SW3# show mac address-table dynamic vlan 3
          Mac Address Table
-------------------------------------------


Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
   3    0200.0101.0101    DYNAMIC     Gi0/2
   3    0200.1111.1111    DYNAMIC     Gi0/1
   3    0200.2222.2222    DYNAMIC     Gi0/1
   3    0200.3333.3333    DYNAMIC     Fa0/13
Total Mac Addresses for this criterion: 4

SW3# show spanning-tree vlan 3 active
VLAN0003
  Spanning tree enabled protocol ieee
  Root ID    Priority    20483
             Address     f47f.35cb.d780
             This bridge is the root
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID  Priority    20483  (priority 20480 sys-id-ext 3)
             Address     f47f.35cb.d780
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec
             Aging Time  300 sec

Interface           Role Sts Cost      Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------------
Fa0/13              Desg FWD 19        128.13   P2p
Gi0/1               Desg FWD 4         128.25   P2p
Gi0/2               Desg FWD 4         128.26   P2p
```

```
! First, note that the broadcast address FFFF.FFFF.FFFF is not
! in the VLAN 3 MAC table.
SW2# show mac address-table dynamic vlan 3
          Mac Address Table
-------------------------------------------


Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
   3    0200.0101.0101    DYNAMIC     Fa0/9
   3    0200.1111.1111    DYNAMIC     Gi0/1
   3    0200.2222.2222    DYNAMIC     Gi0/1
   3    0200.3333.3333    DYNAMIC     Gi0/1
   3    f47f.35cb.d79a    DYNAMIC     Gi0/1
Total Mac Addresses for this criterion: 5

! Next, note that on Fa0/9 and Gi0/1 are in an STP forwarding state,
! and the broadcast came in Gi0/1 - so SW2 floods the frame only out Fa0/9.
SW2# show spanning-tree vlan 3 active
!lines omitted for brevity

Interface        Role Sts Cost      Prio.Nbr Type
---------------- ---- --- --------- -------- --------------------------------
Fa0/9            Desg FWD 19        128.9    P2p
Gi0/1            Root FWD 4         128.25   P2p
Gi0/2            Altn BLK 4         128.26   P2p
```

```
SW2# show mac address-table dynamic vlan 3
          Mac Address Table
-------------------------------------------


Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
   3    0200.0101.0101    DYNAMIC     Fa0/9
   3    0200.1111.1111    DYNAMIC     Gi0/1
   3    0200.2222.2222    DYNAMIC     Gi0/1
   3    0200.3333.3333    DYNAMIC     Gi0/1
   3    f47f.35cb.d79a    DYNAMIC     Gi0/1
Total Mac Addresses for this criterion: 5
```

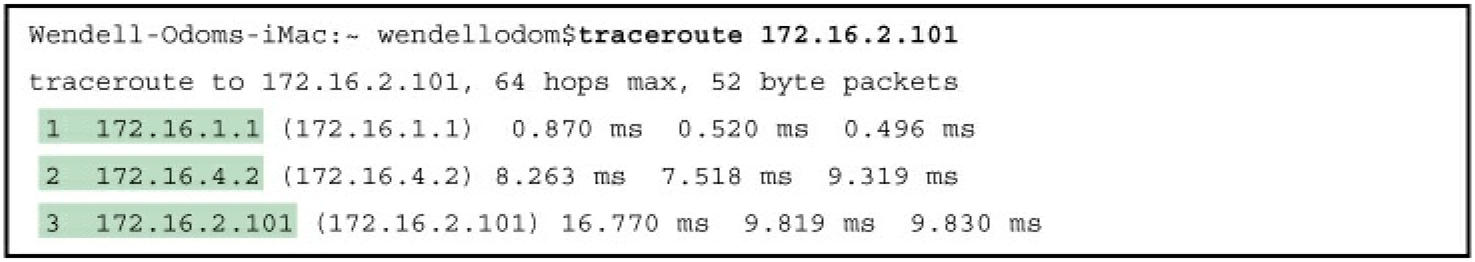
```
SW3# show mac address-table dynamic vlan 3
          Mac Address Table
-------------------------------------------


Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
   3    0200.0101.0101    DYNAMIC     Gi0/2
   3    0200.1111.1111    DYNAMIC     Gi0/1
   3    0200.2222.2222    DYNAMIC     Gi0/1
   3    0200.3333.3333    DYNAMIC     Fa0/13
Total Mac Addresses for this criterion: 4
```

```
SW1# show mac address-table dynamic vlan 3
          Mac Address Table
-------------------------------------------


Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
   3    0200.2222.2222    DYNAMIC     Fa0/12
   3    0200.3333.3333    DYNAMIC     Gi0/2
   3    f47f.35cb.d799    DYNAMIC     Gi0/2
Total Mac Addresses for this criterion: 3

SW1# show mac address-table vlan 3
          Mac Address Table
-------------------------------------------


Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
 All    0100.0ccc.cccc    STATIC      CPU
 All    0100.0ccc.cccd    STATIC      CPU
 All    0180.c200.0000    STATIC      CPU
 All    0180.c200.0001    STATIC      CPU
 All    0180.c200.0002    STATIC      CPU
 All    0180.c200.0003    STATIC      CPU
 All    0180.c200.0004    STATIC      CPU
 All    0180.c200.0005    STATIC      CPU
 All    0180.c200.0006    STATIC      CPU
 All    0180.c200.0007    STATIC      CPU
 All    0180.c200.0008    STATIC      CPU
 All    0180.c200.0009    STATIC      CPU
 All    0180.c200.000a    STATIC      CPU
 All    0180.c200.000b    STATIC      CPU
 All    0180.c200.000c    STATIC      CPU
 All    0180.c200.000d    STATIC      CPU
 All    0180.c200.000e    STATIC      CPU
 All    0180.c200.000f    STATIC      CPU
 All    0180.c200.0010    STATIC      CPU
 All    ffff.ffff.ffff    STATIC      CPU
   3    0200.1111.1111    STATIC      Fa0/11
   3    0200.2222.2222    DYNAMIC     Fa0/12
   3    0200.3333.3333    DYNAMIC     Gi0/2
   3    f47f.35cb.d799    DYNAMIC     Gi0/2
Total Mac Addresses for this criterion: 24
```

```
Wendell-Odoms-iMac:~ wendellodom$ ping 172.16.2.101
PING 172.16.2.101 (172.16.2.101): 56 data bytes
64 bytes from 172.16.2.101: icmp_seq=0 ttl=64 time=1.112 ms
64 bytes from 172.16.2.101: icmp_seq=1 ttl=64 time=0.673 ms
64 bytes from 172.16.2.101: icmp_seq=2 ttl=64 time=0.631 ms
64 bytes from 172.16.2.101: icmp_seq=3 ttl=64 time=0.674 ms
64 bytes from 172.16.2.101: icmp_seq=4 ttl=64 time=0.642 ms
64 bytes from 172.16.2.101: icmp_seq=5 ttl=64 time=0.656 ms
^C
--- 172.16.2.101 ping statistics ---
6 packets transmitted, 6 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 0.631/0.731/1.112/0.171 ms
```

```
R1# ping 172.16.2.101
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.101, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 1/2/4 ms
R1# ping 172.16.2.101
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.101, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/2/4 ms
```

```
R1# ping
Protocol [ip]:
Target IP address: 172.16.2.101
Repeat count [5]:
Datagram size [100]:
Timeout in seconds [2]:
Extended commands [n]: y
Source address or interface: 172.16.1.1
Type of service [0]:
Set DF bit in IP header? [no]:
Validate reply data? [no]:
Data pattern [0xABCD]:
Loose, Strict, Record, Timestamp, Verbose[none]:
Sweep range of sizes [n]:
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.101, timeout is 2 seconds:
Packet sent with a source address of 172.16.1.1
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/2/4 ms
```



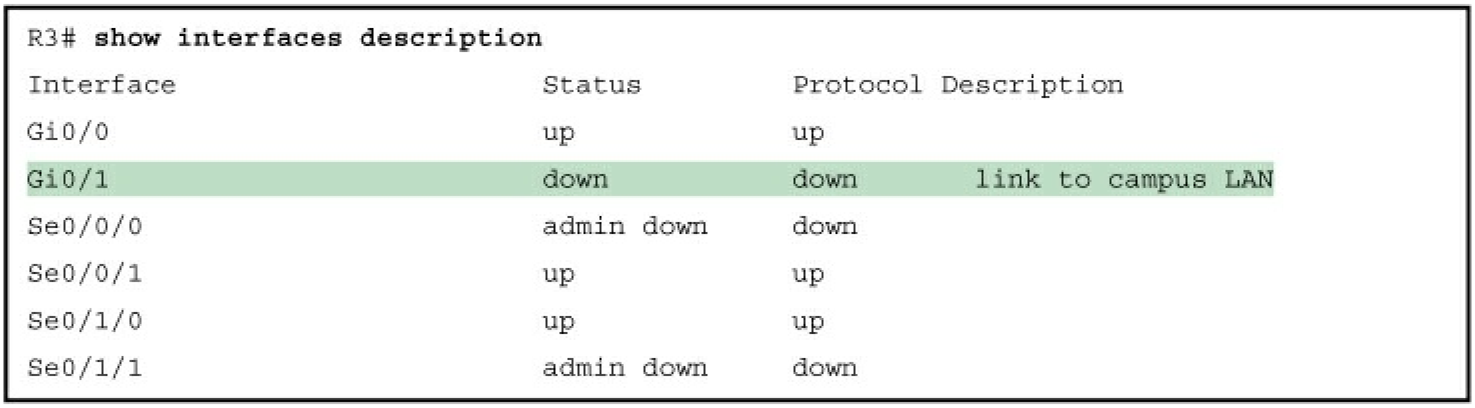
```
Wendell-Odoms-iMac:~ wendellodom$traceroute 172.16.2.101
traceroute to 172.16.2.101, 64 hops max, 52 byte packets
 1  172.16.1.1 (172.16.1.1)  0.870 ms  0.520 ms  0.496 ms
 2  172.16.4.2 (172.16.4.2) 8.263 ms  7.518 ms  9.319 ms
 3  172.16.2.101 (172.16.2.101) 16.770 ms  9.819 ms  9.830 ms
```

```
R1# traceroute 172.16.2.101
Type escape sequence to abort.
Tracing the route to 172.16.2.101
VRF info: (vrf in name/id, vrf out name/id)
  1 172.16.4.2 0 msec 0 msec 0 msec
  2 172.16.2.101 0 msec 0 msec *
```

```
R1# traceroute
Protocol [ip]:
Target IP address: 172.16.2.101
Source address: 172.16.1.1
Numeric display [n]:
Timeout in seconds [3]:
Probe count [3]:
Minimum Time to Live [1]:
Maximum Time to Live [30]:
Port Number [33434]:
Loose, Strict, Record, Timestamp, Verbose[none]:
Type escape sequence to abort.
Tracing the route to 172.16.2.101
VRF info: (vrf in name/id, vrf out name/id)
  1 172.16.4.2 0 msec 0 msec 0 msec
  2 172.16.2.101 0 msec 0 msec *
```

```
R1# show running-config interface g0/0
Building configuration...

Current configuration : 185 bytes
!
interface GigabitEthernet0/0
 description LAN at Site 1
 mac-address 0200.0101.0101
 ip address 10.1.1.150 255.255.255.128
 ip helper-address 10.1.2.130
 duplex auto
 speed auto
end

R1# show ip route connected
! Legend omitted for brevity

      10.0.0.0/8 is variably subnetted, 9 subnets, 4 masks
C        10.1.1.128/25 is directly connected, GigabitEthernet0/0
L        10.1.1.150/32 is directly connected, GigabitEthernet0/0
! Other routes omitted for brevity
```

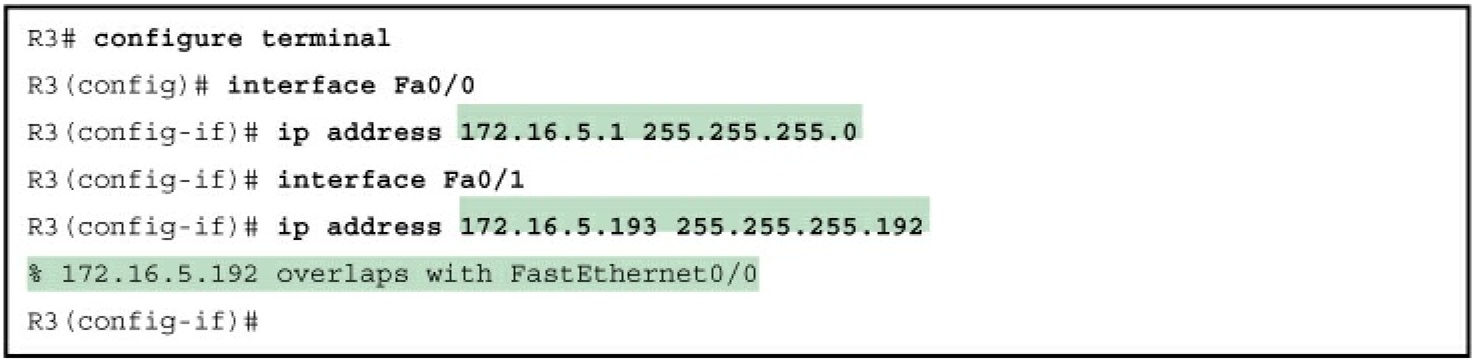
```
interface GigabitEthernet0/1
 ip address 10.1.3.3 255.255.255.192
 ip helper-address 10.1.2.130
!
interface GigabitEthernet0/1.2
 encapsulation dot1q 2
 ip address 10.1.3.65 255.255.255.192
```



```
R3# show interfaces description
Interface                      Status         Protocol Description
Gi0/0                          up             up
Gi0/1                          down           down       link to campus LAN
Se0/0/0                        admin down     down
Se0/0/1                        up             up
Se0/1/0                        up             up
Se0/1/1                        admin down     down
```

```
R1# show ip route ospf
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is 172.16.25.129 to network 0.0.0.0

     172.16.0.0/16 is variably subnetted, 9 subnets, 5 masks
O       172.16.1.1/32 [110/50] via 172.16.25.2, 00:00:04, Serial0/1/1
O       172.16.1.0/24 [110/100] via 172.16.25.129, 00:00:09, Serial0/1/0
O       172.16.0.0/22 [110/65] via 172.16.25.2, 00:00:04, Serial0/1/1
O       172.16.0.0/16 [110/65] via 172.16.25.129, 00:00:09, Serial0/1/0
O       0.0.0.0/0 [110/129] via 172.16.25.129, 00:00:09, Serial0/1/0
!
```

```
R1# show ip route 172.16.4.3
Routing entry for 172.16.0.0/16
  Known via "ospf 1", distance 110, metric 65, type intra area
  Last update from 10.2.2.5 on Serial0/1/0, 14:22:06 ago
  Routing Descriptor Blocks:
  * 172.16.25.129, from 172.16.25.129, 14:22:05 ago, via Serial0/1/0
      Route metric is 65, traffic share count is 1
```



```
R3# configure terminal
R3(config)# interface Fa0/0
R3(config-if)# ip address 172.16.5.1 255.255.255.0
R3(config-if)# interface Fa0/1
R3(config-if)# ip address 172.16.5.193 255.255.255.192
% 172.16.5.192 overlaps with FastEthernet0/0
R3(config-if)#
```

```
! First, on router R2
R2# configure terminal
R2(config)# interface G0/0
R2(config-if)# ip address 172.16.4.1 255.255.254.0
```

```
! Next, on router R3
R3# configure terminal
R3(config)# interface G0/0
R3(config-if)# ip address 172.16.5.1 255.255.255.0
```

```
R1>show ip interface s0/0/1
Serial0/0/1 is up, line protocol is up
  Internet address is 10.1.2.1/24
  Broadcast address is 255.255.255.255
  Address determined by setup command
  MTU is 1500 bytes
  Helper address is not set
  Directed broadcast forwarding is disabled
  Multicast reserved groups joined: 224.0.0.9
  Outgoing access list is not set
  Inbound  access list is 102
! roughly 26 more lines omitted for brevity
```

```
R1# show ip access-lists
Extended IP access list 102
    10 permit ip 10.1.2.0 0.0.0.255 10.1.4.0 0.0.1.255 (15 matches)
```

```
R3# show standby brief
Interface   Grp  Pri P State  Active    Standby         Virtual IP
Gi0/0       1    105   Active local     10.1.12.1       10.1.12.2
```

```
R3# show glbp brief
Interface  Grp  Fwd Pri  State    Address         Active router  Standby router
Gi0/0      1    -   100  Standby  10.1.12.2       10.1.12.4      local
Gi0/0      1    1   -    Active   0007.b400.0101  local          -
Gi0/0      1    2   -    Listen   0007.b400.0102  10.1.12.4      -
```

```
R1# show running-config
! Lines omitted for brevity
interface GigabitEthernet0/0
 ip address 10.1.1.9 255.255.255.0
 standby version 2
 standby 1 ip 10.1.1.1
 standby 1 priority 110
 standby 1 name HSRP-group-for-book
```

```
! The following configuration, on R2, is identical except for the priority,
! the interface IP address, and the HSRP priority
R2# show running-config
! Lines omitted for brevity
interface GigabitEthernet0/0
 ip address 10.1.1.129 255.255.255.0
 standby version 2
 standby 1 ip 10.1.1.1
 standby 1 name HSRP-group-for-book
```

```
! First, the group status as seen from R1
R1# show standby brief
                     P indicates configured to preempt.
                     |
Interface   Grp  Pri P State   Active          Standby         Virtual IP
Gi0/0       1    110   Active  local           10.1.1.129      10.1.1.1
```

```
! The output here on R2 shows that R2 agrees with R1.
R2# show standby brief
                     P indicates configured to preempt.
                     |
Interface   Grp  Pri P State   Active          Standby         Virtual IP
Gi0/0       1    100   Standby 10.1.1.9        local           10.1.1.1
```

```
R1# show standby
GigabitEthernet0/0 - Group 1 (version 2)
  State is Active
    6 state changes, last state change 00:12:53
  Virtual IP address is 10.1.1.1
  Active virtual MAC address is 0000.0c9f.f001
    Local virtual MAC address is 0000.0c9f.f001 (v2 default)
  Hello time 3 sec, hold time 10 sec
    Next hello sent in 1.696 secs
  Preemption disabled
  Active router is local
  Standby router is 10.1.1.129, priority 100 (expires in 8.096 sec)
  Priority 110 (configured 110)
  Group name is "HSRP-group-for-book" (cfgd)
```

```
! The output here on R2 shows that R2 agrees with R1.
R2# show standby
GigabitEthernet0/0 - Group 1 (version 2)
  State is Standby
    4 state changes, last state change 00:12:05
  Virtual IP address is 10.1.1.1
  Active virtual MAC address is 0000.0c9f.f001
    Local virtual MAC address is 0000.0c9f.f001 (v2 default)
  Hello time 3 sec, hold time 10 sec
    Next hello sent in 0.352 secs
  Preemption disabled
  Active router is 10.1.1.9, priority 110 (expires in 9.136 sec)
    MAC address is 0200.0101.0101
  Standby router is local
  Priority 100 (default 100)
  Group name is "HSRP-group-for-book" (cfgd)
```

```
! First, the configuration on R1
R1# show running-config
! Lines omitted for brevity
interface GigabitEthernet0/0
 ip address 10.1.1.9 255.255.255.0
 glbp 1 ip 10.1.1.1
 glbp 1 priority 110
 glbp 1 name GLBP-group-for-book
```

```
! The following configuration, on R2, is identical except for
! the interface IP address, and the GLBP priority
R2# show running-config
! Lines omitted for brevity
interface GigabitEthernet0/0
 ip address 10.1.1.129 255.255.255.0
 glbp 1 ip 10.1.1.1
 glbp 1 name HSRP-group-for-book
```

```
R1# show glbp brief
Interface   Grp  Fwd Pri State    Address         Active router   Standby router
Gi0/0       1    -   110 Active   10.1.1.1        local           10.1.1.129
Gi0/0       1    1   -   Listen   0007.b400.0101  10.1.1.129      -
Gi0/0       1    2   -   Active   0007.b400.0102  local
```

```
R1# show glbp brief
Interface   Grp  Fwd Pri State    Address         Active router   Standby router
Gi0/0       1    -   100 Standby  10.1.1.1        10.1.1.9        local
Gi0/0       1    1   -   Active   0007.b400.0101  local           -
Gi0/0       1    2   -   Listen   0007.b400.0102  10.1.1.9        -
```

```
R1# show glbp
GigabitEthernet0/0 - Group 1
  State is Active
    2 state changes, last state change 00:20:59
  Virtual IP address is 10.1.1.1
  Hello time 3 sec, hold time 10 sec
    Next hello sent in 2.112 secs
  Redirect time 600 sec, forwarder timeout 14400 sec
  Preemption disabled
  Active is local
  Standby is 10.1.1.129, priority 100 (expires in 8.256 sec)
  Priority 110 (configured)
  Weighting 100 (default 100), thresholds: lower 1, upper 100
  Load balancing: round-robin
  IP redundancy name is "GLBP-group-for-book"
  Group members:
    0200.0101.0101 (10.1.1.9) local
    0200.0202.0202 (10.1.1.129)
  There are 2 forwarders (1 active)
  Forwarder 1
    State is Listen
      2 state changes, last state change 00:20:34
    MAC address is 0007.b400.0101 (learnt)
    Owner ID is 0200.0202.0202
    Redirection enabled, 598.272 sec remaining (maximum 600 sec)
    Time to live: 14398.272 sec (maximum 14400 sec)
    Preemption enabled, min delay 30 sec
    Active is 10.1.1.129 (primary), weighting 100 (expires in 8.352 sec)
    Client selection count: 1
  Forwarder 2
    State is Active
      1 state change, last state change 00:24:25
    MAC address is 0007.b400.0102 (default)
    Owner ID is 0200.0101.0101
    Redirection enabled
    Preemption enabled, min delay 30 sec
    Active is local, weighting 100
    Client selection count: 1
```

```
R1# show running-config
! Only the related configuration is listed

interface serial 0/0/0
 ip address 1.1.1.1 255.255.255.0
!
interface Tunnel0
 ip address 10.1.3.1 255.255.255.0
 tunnel source Serial0/0/0
 tunnel destination 2.2.2.2
!
! The OSPF configuration enables OSPF on the tunnel interface as well.
router ospf 1
 network 10.0.0.0 0.255.255.255 area 0
```

```
R2# show running-config
! Only the related configuration is listed
interface serial 0/0/1
 ip address 2.2.2.2 255.255.255.0

!
interface Tunnel1
 ip address 10.1.3.2 255.255.255.0
 tunnel source Serial0/0/1
 tunnel destination 1.1.1.1

! The OSPF configuration enables OSPF on the tunnel interface as well.
router ospf 1
 network 10.0.0.0 0.255.255.255 area 0
```

```
R1# show ip interface brief
Interface                  IP-Address       OK? Method Status                Protocol
GigabitEthernet0/0         10.1.1.9         YES manual up                    up
GigabitEthernet0/1         unassigned       YES manual administratively down down
Serial0/0/0                1.1.1.1          YES manual up                    up
Serial0/0/1                unassigned       YES manual administratively down down
Tunnel0                    10.1.3.1         YES manual up                    up
```

```
R1# show interfaces tunnel0
Tunnel0 is up, line protocol is up
  Hardware is Tunnel
  Internet address is 10.1.3.1/24
  MTU 17916 bytes, BW 100 Kbit/sec, DLY 50000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation TUNNEL, loopback not set
  Keepalive not set
  Tunnel source 1.1.1.1 (Serial0/0/0), destination 2.2.2.2
   Tunnel Subblocks:
      src-track:
         Tunnel0 source tracking subblock associated with Serial0/0/0
          Set of tunnels with source Serial0/0/0, 1 member (includes iterators), on
interface <OK>
  Tunnel protocol/transport GRE/IP
! Lines omitted for brevity
```

```
R1# show ip route 10.0.0.0
Routing entry for 10.0.0.0/8, 5 known subnets
  Attached (4 connections)
  Variably subnetted with 2 masks
C        10.1.1.0/24 is directly connected, GigabitEthernet0/0
L        10.1.1.9/32 is directly connected, GigabitEthernet0/0
O        10.1.2.0/24 [110/1001] via 10.1.3.2, 00:07:55, Tunnel0
C        10.1.3.0/24 is directly connected, Tunnel0
L        10.1.3.1/32 is directly connected, Tunnel0
! Lines omitted for brevity
```

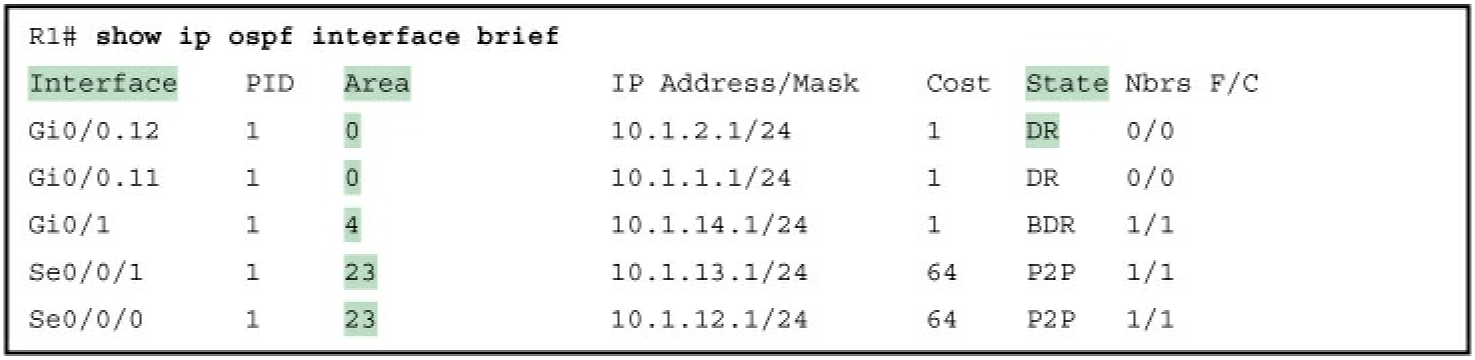
```
R1# traceroute
Protocol [ip]:
Target IP address: 10.1.2.2
Source address: 10.1.1.9
Numeric display [n]:
Timeout in seconds [3]:
Probe count [3]:
Minimum Time to Live [1]:
Maximum Time to Live [30]:
Port Number [33434]:
Loose, Strict, Record, Timestamp, Verbose[none]:
Type escape sequence to abort.
Tracing the route to 10.1.2.2
VRF info: (vrf in name/id, vrf out name/id)
  1 10.1.3.2 0 msec 4 msec 0 msec
  2 10.1.2.2 4 msec 4 msec 0 msec
R1#
```

```
interface GigabitEthernet0/0
 ip address 10.1.23.2 255.255.255.0
!
interface serial 0/0/1
 ip address 10.1.12.2 255.255.255.0
!
router ospf 1
 network 10.0.0.0 0.255.255.255 area 23
 router-id 2.2.2.2
```

```
! First, on R3
interface gigabitEthernet0/0
 ip address 10.1.23.3 255.255.255.0
!
interface serial 0/0/0
 ip address 10.1.13.3 255.255.255.0
!
interface loopback 0
 ip address 3.3.3.3 255.255.255.0
!
router ospf 1
 network 10.0.0.0 0.255.255.255 area 23
```

```
! Next, on R4
interface GigabitEthernet0/0
 description R4 will use this interface for its OSPF RID
 ip address 10.1.14.4 255.255.255.0
!
interface GigabitEthernet0/1
 ip address 10.1.4.4 255.255.255.0
!
router ospf 1
 network 10.0.0.0 0.255.255.255 area 4
 passive-interface gigabitethernet0/1
```

```
interface GigabitEthernet0/0.11
 encapsulation dot1q 11
 ip address 10.1.1.1 255.255.255.0
!
interface GigabitEthernet0/0.12
 encapsulation dot1q 12
 ip address 10.1.2.1 255.255.255.0
!
interface GigabitEthernet0/1
 ip address 10.1.14.1 255.255.255.0
!
interface serial 0/0/0
 ip address 10.1.12.1 255.255.255.0
!
interface serial 0/0/1
 ip address 10.1.13.1 255.255.255.0
!
router ospf 1
 network 10.1.1.1 0.0.0.0 area 0
 network 10.1.2.1 0.0.0.0 area 0
 network 10.1.12.1 0.0.0.0 area 23
 network 10.1.13.1 0.0.0.0 area 23
 network 10.1.14.1 0.0.0.0 area 4
 router-id 1.1.1.1
 passive-interface gigabitethernet0/0.11
 passive-interface gigabitethernet0/0.12
```



```
R1# show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Gi0/0.12     1     0               10.1.2.1/24        1     DR    0/0
Gi0/0.11     1     0               10.1.1.1/24        1     DR    0/0
Gi0/1        1     4               10.1.14.1/24       1     BDR   1/1
Se0/0/1      1     23              10.1.13.1/24       64    P2P   1/1
Se0/0/0      1     23              10.1.12.1/24       64    P2P   1/1
```

```
R4# show ip ospf interface gigabitEthernet 0/0
GigabitEthernet0/0 is up, line protocol is up
  Internet Address 10.1.14.4/24, Area 4, Attached via Network Statement
  Process ID 1, Router ID 10.1.14.4, Network Type BROADCAST, Cost: 1
  Topology-MTID    Cost    Disabled    Shutdown      Topology Name
        0           1         no          no            Base
  Transmit Delay is 1 sec, State DR, Priority 1
  Designated Router (ID) 10.1.14.4, Interface address 10.1.14.4
  Backup Designated router (ID) 1.1.1.1, Interface address 10.1.14.1
!
! Lines omitted for brevity
R4# show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
1.1.1.1           1   FULL/BDR        00:00:33    10.1.14.1       GigabitEthernet0/0
```

```
R4# show ip ospf database

            OSPF Router with ID (10.1.14.4) (Process ID 1)

                Router Link States (Area 4)

Link ID         ADV Router      Age         Seq#       Checksum Link count
1.1.1.1         1.1.1.1         1252        0x80000015 0x00AE30 1
10.1.14.4       10.1.14.4       1453        0x80000015 0x00A2E7 2

                Net Link States (Area 4)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.14.4       10.1.14.4       1453        0x80000014 0x007259

                Summary Net Link States (Area 4)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.1.0        1.1.1.1         1493        0x80000014 0x00B563
10.1.2.0        1.1.1.1         1493        0x80000014 0x00AA6D
10.1.12.0       1.1.1.1         1493        0x80000014 0x00B41A
10.1.13.0       1.1.1.1         1493        0x80000014 0x00A924
10.1.23.0       1.1.1.1         1493        0x80000014 0x00457D
```

```
R4# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

      10.0.0.0/8 is variably subnetted, 9 subnets, 2 masks
O IA     10.1.1.0/24 [110/2] via 10.1.14.1, 11:04:43, GigabitEthernet0/0
O IA     10.1.2.0/24 [110/2] via 10.1.14.1, 11:04:43, GigabitEthernet0/0
C        10.1.4.0/24 is directly connected, GigabitEthernet0/1
L        10.1.4.4/32 is directly connected, GigabitEthernet0/1
O IA     10.1.12.0/24 [110/65] via 10.1.14.1, 11:04:43, GigabitEthernet0/0
O IA     10.1.13.0/24 [110/65] via 10.1.14.1, 11:04:43, GigabitEthernet0/0
C        10.1.14.0/24 is directly connected, GigabitEthernet0/0
L        10.1.14.4/32 is directly connected, GigabitEthernet0/0
O IA     10.1.23.0/24 [110/66] via 10.1.14.1, 11:04:43, GigabitEthernet0/0
```

```
R1# show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Gi0/0.12     1     0               10.1.2.1/24        1     DR    0/0
Gi0/0.11     1     0               10.1.1.1/24        1     DR    0/0
Gi0/1        1     4               10.1.14.1/24       1     BDR   1/1
Se0/0/1      1     23              10.1.13.1/24       64    P2P   1/1
Se0/0/0      1     23              10.1.12.1/24       64    P2P   1/1
```

```
EIGRP-IPv4 Neighbors for AS(1)
H   Address             Interface        Hold Uptime   SRTT   RTO  Q  Seq
                                         (sec)         (ms)       Cnt Num
1   10.1.4.3            Se0/0/1          13 00:05:49    2     100  0  29
0   10.1.5.2            Se0/0/0          12 00:05:49    2     100  0  39
```

```
P 10.1.1.0/24, 1 successors, FD is 2172416
         via 10.1.6.3 (2172416/28160), Serial0/1
         via 10.1.4.2 (2684416/2284156), Serial0/0
         via 10.1.5.4 (2684416/2165432), Serial1/0
```

```
R3(config)# router eigrp 1
R3(config-router)# network 10.1.3.0 0.0.0.255
R3(config-router)# network 10.1.4.0 0.0.0.255
R3(config-router)# network 10.1.6.0 0.0.0.255
```

```
R1# show ip eigrp interfaces
EIGRP-IPv4 Interfaces for AS(1)
                 Xmit Queue  PeerQ        Mean Pacing Time  Multicast  Pending
Interface Peers  Un/Reliable Un/Reliable  SRTT Un/Reliable  Flow Timer Routes
Gi0/0        0       0/0       0/0          0     0/0            0         0
Se0/0/0      1       0/0       0/0          2     0/16          50         0
Se0/0/1      1       0/0       0/0          1     0/15          50         0

R1# show ip eigrp interfaces detail S0/0/0
EIGRP-IPv4 Interfaces for AS(1)
                  Xmit Queue  PeerQ       Mean Pacing Time Multicast  Pending
Interface  Peers  Un/Reliable Un/Reliable SRTT Un/Reliable Flow Timer Routes
Se0/0/0      1        0/0       0/0         2     0/16         50         0
  Hello-interval is 5, Hold-time is 15
  Split-horizon is enabled
! lines omitted for brevity
```

```
R1# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "eigrp 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Default networks flagged in outgoing updates
  Default networks accepted from incoming updates
  EIGRP-IPv4 Protocol for AS(1)
    Metric weight K1=1, K2=0, K3=1, K4=0, K5=0
    NSF-aware route hold timer is 240
    Router-ID: 10.1.5.1
    Topology : 0 (base)
      Active Timer: 3 min
      Distance: internal 90 external 170
      Maximum path: 4
      Maximum hopcount 100
      Maximum metric variance 1

  Automatic Summarization: disabled
  Maximum path: 4
  Routing for Networks:
    10.0.0.0
  Routing Information Sources:
    Gateway         Distance      Last Update
    10.1.4.3              90      00:22:32
    10.1.5.2              90      00:22:32
  Distance: internal 90 external 170
```

```
R3# show ip protocols
! Lines omitted for brevity

  Automatic Summarization: disabled
  Maximum path: 4
  Routing for Networks:
    10.1.3.0/24
    10.1.4.0/24
    10.1.6.0/24
! Lines omitted for brevity
```

```
R1# show ip eigrp neighbors
EIGRP-IPv4 Neighbors for AS(1)
H   Address                 Interface              Hold Uptime   SRTT   RTO  Q  Seq
                                                   (sec)         (ms)       Cnt Num
1   10.1.4.3                Se0/0/1                  13 00:05:49    2   100  0  29
0   10.1.5.2                Se0/0/0                  12 00:05:49    2   100  0  39
```

```
R1# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      10.0.0.0/8 is variably subnetted, 9 subnets, 2 masks
C        10.1.1.0/24 is directly connected, GigabitEthernet0/0
L        10.1.1.1/32 is directly connected, GigabitEthernet0/0
D        10.1.2.0/24 [90/2172416] via 10.1.5.2, 00:06:39, Serial0/0/0
D        10.1.3.0/24 [90/2172416] via 10.1.4.3, 00:00:06, Serial0/0/1
C        10.1.4.0/24 is directly connected, Serial0/0/1
L        10.1.4.1/32 is directly connected, Serial0/0/1
C        10.1.5.0/24 is directly connected, Serial0/0/0
L        10.1.5.1/32 is directly connected, Serial0/0/0
D        10.1.6.0/24 [90/2681856] via 10.1.5.2, 00:12:20, Serial0/0/0
                     [90/2681856] via 10.1.4.3, 00:12:20, Serial0/0/1

R1# show ip route eigrp
! Legend omitted for brevity

      10.0.0.0/8 is variably subnetted, 9 subnets, 2 masks
D        10.1.2.0/24 [90/2172416] via 10.1.5.2, 00:06:43, Serial0/0/0
D        10.1.3.0/24 [90/2172416] via 10.1.4.3, 00:00:10, Serial0/0/1
D        10.1.6.0/24 [90/2681856] via 10.1.5.2, 00:12:24, Serial0/0/0
                     [90/2681856] via 10.1.4.3, 00:12:24, Serial0/0/1
```

```
R1# show ip eigrp topology
EIGRP-IPv4 Topology Table for AS(1)/ID(10.1.5.1)
Codes: P - Passive, A - Active, U - Update, Q - Query, R - Reply,
       r - reply Status, s - sia Status

P 10.1.5.0/24, 1 successors, FD is 2169856
        via Connected, Serial0/0/0
P 10.1.7.0/24, 1 successors, FD is 2681856
        via 10.1.4.3 (2681856/2169856), Serial0/0/1
P 10.1.3.0/24, 1 successors, FD is 2172416
        via 10.1.4.3 (2172416/28160), Serial0/0/1
P 10.1.2.0/24, 1 successors, FD is 2172416
        via 10.1.5.2 (2172416/28160), Serial0/0/0
P 10.1.6.0/24, 2 successors, FD is 2681856
        via 10.1.4.3 (2681856/2169856), Serial0/0/1
        via 10.1.5.2 (2681856/2169856), Serial0/0/0
P 10.1.4.0/24, 1 successors, FD is 2169856
        via Connected, Serial0/0/1
P 10.1.33.0/24, 2 successors, FD is 2684416
        via 10.1.4.3 (2684416/2172416), Serial0/0/1
        via 10.1.5.2 (2684416/2172416), Serial0/0/0
P 10.1.1.0/24, 1 successors, FD is 28160
        via Connected, GigabitEthernet0/0
P 10.1.8.0/24, 1 successors, FD is 2681856
        via 10.1.5.2 (2681856/2169856), Serial0/0/0
```

```
R1# show ip eigrp topology | section 10.1.33.0
P 10.1.33.0/24, 2 successors, FD is 2684416
        via 10.1.4.3 (2684416/2172416), Serial0/0/1
        via 10.1.5.2 (2684416/2172416), Serial0/0/0
```

```
R2# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R2(config)# interface s0/1/0
R2(config-if)# bandwidth 1400
```

```
R1# show ip eigrp topology | section 10.1.33.0
P 10.1.33.0/24, 1 successors, FD is 2684416
        via 10.1.4.3 (2684416/2172416), Serial0/0/1
        via 10.1.5.2 (2854912/2342912), Serial0/0/0
```

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
! Below, debug eigrp fsm is enabled, and then R3's S0/1/0 link to R4 is disabled,
! but not shown in the example text. SOME DEBUG MESSAGES are omitted to
! improve readability.
R1# debug eigrp fsm
EIGRP FSM Events/Actions debugging is on
R1#
*Nov 13 23:50:41.099: EIGRP-IPv4(1): Find FS for dest 10.1.33.0/24. FD is 2684416, RD
is 2684416 on tid 0
*Nov 13 23:50:41.099: EIGRP-IPv4(1):    10.1.4.3 metric 72057594037927935/72057594037
927936
*Nov 13 23:50:41.099: EIGRP-IPv4(1):    10.1.5.2 metric 2854912/2342912 found Dmin is
2854912
*Nov 13 23:50:41.099: DUAL: AS(1) RT installed 10.1.33.0/24 via 10.1.5.2
!
! Next, R1 lists a new successor route, to 10.1.5.2: R2.
R1# show ip eigrp topology | section 10.1.33.0
P 10.1.33.0/24, 1 successors, FD is 2854912
        via 10.1.5.2 (2854912/2342912), Serial0/0/0
R1# show ip route | section 10.1.33.0
D        10.1.33.0/24 [90/2854912] via 10.1.5.2, 00:16:50, Serial0/0/0
```

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
R1# show ip eigrp topology 10.1.3.0/24
EIGRP-IPv4 Topology Entry for AS(1)/ID(10.1.13.1) for 10.1.3.0/24
  State is Passive, Query origin flag is 1, 1 Successor(s), FD is 2172416
  Descriptor Blocks:
  10.1.4.3 (Serial0/0/1), from 10.1.4.3, Send flag is 0x0
      Composite metric is (2172416/28160), route is Internal
      Vector metric:
        Minimum bandwidth is 1544 Kbit
        Total delay is 20100 microseconds
        Reliability is 255/255
        Load is 1/255
        Minimum MTU is 1500
        Hop count is 1
        Originating router is 3.3.3.3
  10.1.5.2 (Serial0/0/0), from 10.1.5.2, Send flag is 0x0
      Composite metric is (2684416/2172416), route is Internal
      Vector metric:
        Minimum bandwidth is 1544 Kbit
        Total delay is 40100 microseconds
        Reliability is 255/255
        Load is 1/255
        Minimum MTU is 1500
        Hop count is 2
```

```
R1# show ip eigrp topology | section 10.1.33.0
P 10.1.33.0/24, 2 successors, FD is 2684416
        via 10.1.4.3 (2684416/2172416), Serial0/0/1
        via 10.1.5.2 (2684416/2172416), Serial0/0/0

R1# show ip route | section 10.1.33.0
D        10.1.33.0/24 [90/2684416] via 10.1.5.2, 00:02:23, Serial0/0/0
                      [90/2684416] via 10.1.4.3, 00:02:23, Serial0/0/1
```

```
Yosemite# show interfaces fa0/0
FastEthernet0/0 is up, line protocol is up
  Hardware is Gt96k FE, address is 0013.197b.5026 (bia 0013.197b.5026)
  Internet address is 10.1.2.252/24
  MTU 1500 bytes, BW 100000 Kbit, DLY 100 usec,
! lines omitted for brevity

Yosemite# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Yosemite(config)# interface fa0/0
Yosemite(config-if)# delay 123
Yosemite(config-if)# ^Z
Yosemite# show interfaces fa0/0
FastEthernet0/0 is up, line protocol is up
  Hardware is Gt96k FE, address is 0013.197b.5026 (bia 0013.197b.5026)
  Internet address is 10.1.2.252/24
  MTU 1500 bytes, BW 100000 Kbit, DLY 1230 usec,
! lines omitted for brevity
```

```
R2# show ip route eigrp
! lines omitted for brevity

D      10.0.0.0/8 [90/2297856] via 172.16.3.3, 00:12:59, Serial0/0/0
```

```
R2# show ip route | section 10.0.0.0
D     10.0.0.0/8 [90/2297856] via 172.16.3.3, 00:00:15, Serial0/0/0
                 [90/2297856] via 172.16.2.1, 00:00:15, Serial0/0/1
```

```
R2# show ip route 10.0.0.0
Routing entry for 10.0.0.0/24, 8 known subnets
  Redistributing via eigrp 1
D        10.2.1.0 [90/2297856] via 172.16.2.1, 00:00:12, Serial0/0/1
D        10.2.2.0 [90/2297856] via 172.16.2.1, 00:00:12, Serial0/0/1
D        10.2.3.0 [90/2297856] via 172.16.2.1, 00:00:12, Serial0/0/1
D        10.2.4.0 [90/2297856] via 172.16.2.1, 00:00:12, Serial0/0/1
D        10.3.4.0 [90/2297856] via 172.16.3.3, 00:00:06, Serial0/0/0
D        10.3.5.0 [90/2297856] via 172.16.3.3, 00:00:06, Serial0/0/0
D        10.3.6.0 [90/2297856] via 172.16.3.3, 00:00:06, Serial0/0/0
D        10.3.7.0 [90/2297856] via 172.16.3.3, 00:00:06, Serial0/0/0
```

```
R1# show running-config
! only pertinent lines shown
router eigrp 99
 network 10.0.0.0
!
R1# show ip eigrp interfaces
EIGRP-IPv4 Interfaces for AS(99)
                   Xmit Queue   PeerQ        Mean   Pacing Time   Multicast    Pending
Interface   Peers  Un/Reliable  Un/Reliable  SRTT   Un/Reliable   Flow Timer   Routes
Gi0/0         3        0/0         0/0         2        0/0           50          0
Gi0/1         0        0/0         0/0         0        0/0            0          0

R1# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "eigrp 99"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Default networks flagged in outgoing updates
  Default networks accepted from incoming updates
  EIGRP-IPv4 Protocol for AS(99)
```

```
    Metric weight K1=1, K2=0, K3=1, K4=0, K5=0
    NSF-aware route hold timer is 240
    Router-ID: 1.1.1.1
    Topology : 0 (base)
      Active Timer: 3 min
      Distance: internal 90 external 170
      Maximum path: 4
      Maximum hopcount 100
      Maximum metric variance 1

  Automatic Summarization: disabled
  Maximum path: 4
  Routing for Networks:
    10.0.0.0
  Routing Information Sources:
    Gateway         Distance      Last Update
    10.1.1.2              90      09:55:51
    10.1.1.3              90      00:02:00
  Distance: internal 90 external 170

R1# show ip route eigrp
! Legend omitted for brevity

      10.0.0.0/8 is variably subnetted, 5 subnets, 2 masks
D        10.1.22.0/24 [90/30720] via 10.1.1.2, 00:00:40, GigabitEthernet0/0
```

```
R2# show running-config
! only pertinent lines shown
router eigrp 99
 network 10.1.0.0 0.0.255.255

R2# show ip eigrp interfaces
EIGRP-IPv4 Interfaces for AS(99)
                   Xmit Queue   PeerQ        Mean   Pacing Time   Multicast    Pending
Interface   Peers  Un/Reliable  Un/Reliable  SRTT   Un/Reliable   Flow Timer   Routes
Gi0/0           2      0/0         0/0          1       0/1           50          0
Gi0/1           0      0/0         0/0          0       0/0            0          0

R2# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "eigrp 99"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Default networks flagged in outgoing updates
  Default networks accepted from incoming updates
  EIGRP-IPv4 Protocol for AS(99)
    Metric weight K1=1, K2=0, K3=1, K4=0, K5=0
    NSF-aware route hold timer is 240
    Router-ID: 2.2.2.2
    Topology : 0 (base)
      Active Timer: 3 min
      Distance: internal 90 external 170
      Maximum path: 4
      Maximum hopcount 100
      Maximum metric variance 1

  Automatic Summarization: disabled
  Maximum path: 4
  Routing for Networks:
    10.1.0.0/16
  Routing Information Sources:
    Gateway         Distance      Last Update
    10.1.1.3              90      00:02:30
    10.1.1.1              90      09:56:20
  Distance: internal 90 external 170

R2# show ip route eigrp
! Legend omitted for brevity
      10.0.0.0/8 is variably subnetted, 5 subnets, 2 masks
D        10.1.11.0/24 [90/30720] via 10.1.1.1, 00:03:25, GigabitEthernet0/0
```

```
R3# show running-config
! lines omitted for brevity
router eigrp 99
 network 10.1.1.3 0.0.0.0
 network 10.1.13.3 0.0.0.0
 auto-summary

R3# show ip eigrp interfaces
EIGRP-IPv4 Interfaces for AS(99)
                   Xmit Queue   PeerQ        Mean   Pacing Time   Multicast    Pending
Interface   Peers  Un/Reliable  Un/Reliable  SRTT   Un/Reliable   Flow Timer   Routes
Gi0/0         2        0/0          0/0         1       0/1           50           0

R3# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "eigrp 99"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Default networks flagged in outgoing updates
  Default networks accepted from incoming updates
  EIGRP-IPv4 Protocol for AS(99)
    Metric weight K1=1, K2=0, K3=1, K4=0, K5=0
    NSF-aware route hold timer is 240
    Router-ID: 3.3.3.3
    Topology : 0 (base)
      Active Timer: 3 min
      Distance: internal 90 external 170
      Maximum path: 4
      Maximum hopcount 100
      Maximum metric variance 1
  Automatic Summarization: disabled
  Maximum path: 4
  Routing for Networks:
    10.1.1.3/32
    10.1.13.3/32
  Routing Information Sources:
    Gateway         Distance      Last Update
    10.1.1.2              90      00:05:14
    10.1.1.1              90      00:05:14
  Distance: internal 90 external 170
```

```
R4# show running-config
! lines omitted for brevity
router eigrp 99
 passive-interface GigabitEthernet0/0
 network 10.0.0.0
 auto-summary

R4# show ip eigrp interfaces
EIGRP-IPv4 Interfaces for AS(99)
                   Xmit Queue   PeerQ        Mean   Pacing Time   Multicast    Pending
Interface   Peers  Un/Reliable  Un/Reliable  SRTT   Un/Reliable   Flow Timer   Routes
Gi0/1         0        0/0          0/0        0        0/1           0           0

R4# show ip protocols | begin Routing for Networks
  Routing for Networks:
    10.0.0.0
  Passive Interface(s):
    GigabitEthernet0/0
  Routing Information Sources:
    Gateway         Distance      Last Update
  Distance: internal 90 external 170
```

```
R1> show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Gi0/1        1     0               10.1.11.1/24       1     DR    0/0
Gi0/0        1     0               10.1.1.1/24        1     DROTH 2/2
```

```
! The following command is from R2
R2> show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Gi0/1        2     1               10.1.22.2/24       1     WAIT  0/0
Gi0/0        2     1               10.1.1.2/24        1     WAIT  0/0
```

```
R1> show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "ospf 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 1.1.1.1
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    10.0.0.0 0.255.255.255 area 0
  Routing Information Sources:
    Gateway         Distance      Last Update
    2.2.2.2              110      00:14:32
    3.3.3.3              110      00:14:32
    10.1.44.4            110      00:14:42
  Distance: (default is 110)
R1> show ip route ospf
! Legend omitted for brevity

      10.0.0.0/8 is variably subnetted, 6 subnets, 2 masks
O        10.1.33.0/24 [110/2] via 10.1.1.3, 00:15:32, GigabitEthernet0/0
O        10.1.44.0/24 [110/2] via 10.1.1.4, 00:15:42, GigabitEthernet0/0
```

```
! Now moving to router R2

R2> show ip protocols
```

```
*** IP Routing is NSF aware ***

Routing Protocol is "ospf 2"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 2.2.2.2
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    10.0.0.0 0.255.255.255 area 1
  Routing Protocol is "ospf 2"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 2.2.2.2
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    10.0.0.0 0.255.255.255 area 1
  Routing Information Sources:
    Gateway         Distance      Last Update
  Distance: (default is 110)

R2>
Nov 15 12:16:39.377: %OSPF-4-ERRRCV: Received invalid packet: mismatched area
ID, from backbone area must be virtual-link but not found from 10.1.1.1,
GigabitEthernet0/0
```

```
R1# show ip eigrp neighbors
EIGRP-IPv4 Neighbors for AS(99)
H   Address                 Interface              Hold Uptime   SRTT   RTO  Q  Seq
                                                   (sec)         (ms)       Cnt Num
1   10.1.1.3                Gi0/0                    13 00:00:20    1   100  0  31
2   10.1.1.4                Gi0/0                    13 00:00:43   80   480  0  10
0   10.1.1.2                Gi0/0                    13 00:13:52    1   100  0  20
```

```
! First, R1 has no neighbor relationships yet. R1 uses ASN (process) 99.
R1# show ip eigrp neighbors
EIGRP-IPv4 Neighbors for AS(99)

R1#
! Next, R1 generates a log message, which shows up at the console, stating
! that the router with IP address 10.1.2.2 is not on the same subnet as R1.
!
*Nov 15 16:19:14.740: %DUAL-6-NBRINFO: EIGRP-IPv4 99: Neighbor 10.1.2.2
(GigabitEthernet0/0) is blocked: not on common subnet (10.1.1.1/24)

! Next, R1 enables a debug that shows messages for each packet received from R4,
! which uses the wrong password (authentication key string)
!
R1# debug eigrp packets
EIGRP Packets debugging is on
    (UPDATE, REQUEST, QUERY, REPLY, HELLO, IPXSAP, PROBE, ACK, STUB, SIAQUERY,
     SIAREPLY)
R1#

*Nov 15 16:20:30.865: EIGRP: Gi0/0: ignored packet from 10.1.1.4, opcode = 5 (authen-
tication off or key-chain missing)
```

```
R3# show ip protocols
Routing Protocol is "eigrp 199"
!
! The first line of output from show ip eigrp interfaces lists ASN 199
!
R3# show ip eigrp interfaces
EIGRP-IPv4 Interfaces for AS(199)
                        Xmit Queue   Mean   Pacing Time   Multicast    Pending
Interface        Peers  Un/Reliable  SRTT   Un/Reliable   Flow Timer   Routes
Gi0/0              0        0/0         0       0/1            0           0
Gi0/1              0        0/0         0       0/1            0           0
```

```
R2# show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
1.1.1.1           1   FULL/BDR        00:00:37    10.1.1.1        GigabitEthernet0/0
3.3.3.3           1   2WAY/DROTHER    00:00:37    10.1.1.3        GigabitEthernet0/0
4.4.4.4           1   FULL/DR         00:00:31    10.1.1.4        GigabitEthernet0/0
```

```
R1# debug ip ospf adj
OSPF adjacency events debugging is on
R1#
*Nov 15 13:42:02.288: OSPF-1 ADJ   Gi0/0: Rcv pkt from 10.1.1.2, area 0.0.0.0, mis-
matched area 0.0.0.1 in the header
R1#
R1# undebug all
All possible debugging has been turned off
```

```
! Next, on R3: ! R3 lists the RID of 1.1.1.1
!
R3# show ip ospf
 Routing Process "ospf 3" with ID 1.1.1.1
 Start time: 00:00:37.136, Time elapsed: 02:20:37.200
! lines omitted for brevity
```

```
! Back to R1: R1 also uses RID 1.1.1.1

R1# show ip ospf
 Routing Process "ospf 1" with ID 1.1.1.1
 Start time: 00:01:51.864, Time elapsed: 12:13:50.904
 Supports only single TOS(TOS0) routes
 Supports opaque LSA
 Supports Link-local Signaling (LLS)
 Supports area transit capability
 Supports NSSA (compatible with RFC 3101)
 Event-log enabled, Maximum number of events: 1000, Mode: cyclic
 Router is not originating router-LSAs with maximum metric
 Initial SPF schedule delay 5000 msecs
 Minimum hold time between two consecutive SPFs 10000 msecs
 Maximum wait time between two consecutive SPFs 10000 msecs
 Incremental-SPF disabled
 Minimum LSA interval 5 secs
 Minimum LSA arrival 1000 msecs
 LSA group pacing timer 240 secs
 Interface flood pacing timer 33 msecs
 Retransmission pacing timer 66 msecs
 Number of external LSA 0. Checksum Sum 0x000000
 Number of opaque AS LSA 0. Checksum Sum 0x000000
 Number of DCbitless external and opaque AS LSA 0
 Number of DoNotAge external and opaque AS LSA 0
 Number of areas in this router is 1. 1 normal 0 stub 0 nssa
 Number of areas transit capable is 0
 External flood list length 0
 IETF NSF helper support enabled
 Cisco NSF helper support enabled
 Reference bandwidth unit is 100 mbps
    Area BACKBONE(0) (Inactive)
        Number of interfaces in this area is 3
        Area has no authentication
        SPF algorithm last executed 00:52:42.956 ago
        SPF algorithm executed 9 times
        Area ranges are
        Number of LSA 1. Checksum Sum 0x00C728
        Number of opaque link LSA 0. Checksum Sum 0x000000
        Number of DCbitless LSA 0
        Number of indication LSA 0
        Number of DoNotAge LSA 0
        Flood list length 0

*May 29 00:01:25.679: %OSPF-4-DUP_RTRID_NBR: OSPF detected duplicate router-id
1.1.1.1 from 10.1.1.3 on interface GigabitEthernet0/0
```

```
R1# show ip ospf interface G0/0
GigabitEthernet0/0 is up, line protocol is up
  Internet Address 10.1.1.1/24, Area 0, Attached via Network Statement
  Process ID 1, Router ID 1.1.1.1, Network Type BROADCAST, Cost: 1
  Topology-MTID    Cost    Disabled    Shutdown      Topology Name
        0           1          no          no            Base
  Transmit Delay is 1 sec, State DR, Priority 1
  Designated Router (ID) 1.1.1.1, Interface address 10.1.1.1
  No backup designated router on this network
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
! lines omitted for brevity
```

```
! Moving on to R4 next
!
R4# show ip ospf interface Gi0/0
GigabitEthernet0/0 is up, line protocol is up
  Internet Address 10.1.1.4/24, Area 0, Attached via Network Statement
  Process ID 4, Router ID 10.1.44.4, Network Type BROADCAST, Cost: 1
  Topology-MTID    Cost    Disabled    Shutdown      Topology Name
        0           1          no          no            Base
  Transmit Delay is 1 sec, State DR, Priority 1
  Designated Router (ID) 10.1.44.4, Interface address 10.1.1.4
  No backup designated router on this network
  Timer intervals configured, Hello 5, Dead 20, Wait 20, Retransmit 5
! lines omitted for brevity
```

```
R1# debug ip ospf hello
OSPF hello events debugging is on
R1#
*Nov 15 14:05:10.616: OSPF-1 HELLO Gi0/0: Rcv hello from 10.1.44.4 area 0 10.1.1.4
*Nov 15 14:05:10.616: OSPF-1 HELLO Gi0/0: Mismatched hello parameters from 10.1.1.4
*Nov 15 14:05:10.616: OSPF-1 HELLO Gi0/0: Dead R 20 C 40, Hello R 5 C 10 Mask R
255.255.255.0 C 255.255.255.0
```

```
R1# show ip ospf interface g0/0
GigabitEthernet0/0 is up, line protocol is up
  Internet Address 10.1.1.1/24, Area 0, Attached via Network Statement
  Process ID 1, Router ID 1.1.1.1, Network Type BROADCAST, Cost: 1
! Lines omitted for brevity
```

```
R1# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R1(config)# interface gigabitethernet0/0
R1(config-if)# ip ospf network point-to-point
R1(config-if)# ^Z
R1#
R1# show ip route ospf
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

R1#
! Lines omitted for brevity
```

```
Serial0/0/1 is up, line protocol is up
  Hardware is GT96K Serial
  Internet address is 192.168.2.1/24
  MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation PPP, LCP Open
  Open: CDPCP, IPCP, loopback not set
```

```
R1# show running-config
! Note - only the related lines are shown
interface GigabitEthernet0/0
 ip address 192.168.1.1 255.255.255.0
!
interface Serial0/0/0
 ip address 192.168.2.1 255.255.255.0
 description link to R2
 clock rate 2000000
!
router eigrp 1
 network 192.168.1.0
 network 192.168.2.0
```

```
R1# show controllers serial 0/0/0
Interface Serial0/0/0
Hardware is SCC
DCE V.35, clock rate 2000000
! lines omitted for brevity

R1# show interfaces s0/0/0
Serial0/0/0 is up, line protocol is up
  Hardware is WIC MBRD Serial
  Description: link to R2
  Internet address is 192.168.2.1/24
  MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation HDLC, loopback not set
  Keepalive set (10 sec)
  Last input 00:00:01, output 00:00:00, output hang never
  Last clearing of "show interface" counters never
  Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
  Queueing strategy: fifo
  Output queue: 0/40 (size/max)
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
     276 packets input, 19885 bytes, 0 no buffer
     Received 96 broadcasts (0 IP multicasts)
     0 runts, 0 giants, 0 throttles
     0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored, 0 abort
     284 packets output, 19290 bytes, 0 underruns
     0 output errors, 0 collisions, 5 interface resets
     0 unknown protocol drops
     0 output buffer failures, 0 output buffers swapped out
     7 carrier transitions
     DCD=up  DSR=up  DTR=up  RTS=up  CTS=up
```

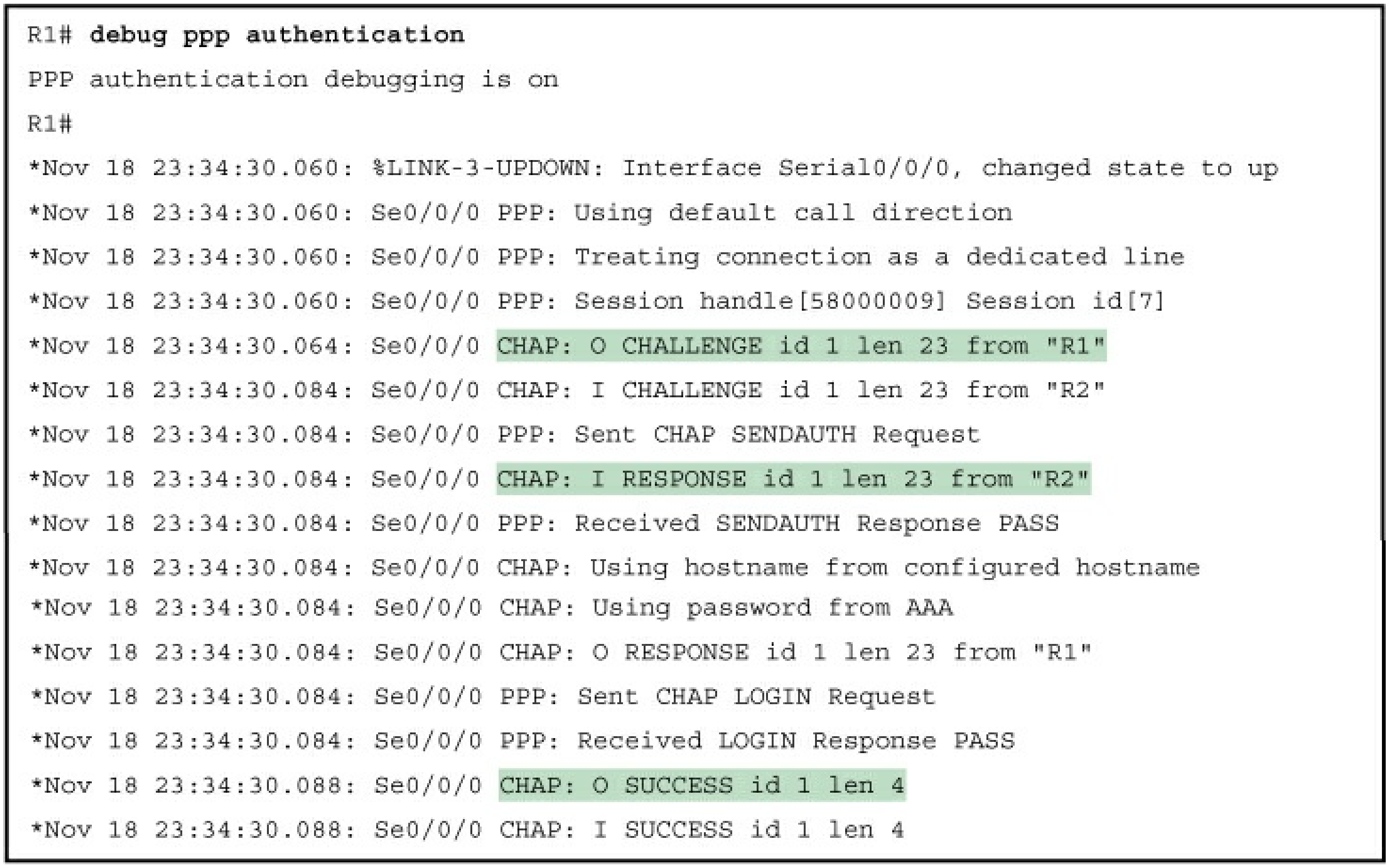
```
R1# show ip interface brief
Interface                  IP-Address      OK? Method Status                Protocol
GigabitEthernet0/0         192.168.1.1     YES manual up                    up
GigabitEthernet0/1         unassigned      YES manual administratively down down
Serial0/0/0                192.168.2.1     YES manual up                    up
Serial0/0/1                unassigned      YES NVRAM  administratively down down
Serial0/1/0                unassigned      YES NVRAM  administratively down down
Serial0/1/1                unassigned      YES NVRAM  administratively down down

R1# show interfaces description
Interface                      Status         Protocol Description
Gi0/0                          up             up       LAN at Site 1
Gi0/1                          admin down     down
Se0/0/0                        up             up       link to R2
Se0/0/1                        admin down     down
Se0/1/0                        admin down     down
Se0/1/1                        admin down     down
```

```
! The example starts with router R1
interface Serial0/0/0
 ip address 192.168.2.1 255.255.255.0
 encapsulation ppp
 clockrate 2000000
```

```
! Next, the configuration on router R2
interface Serial0/0/1
 ip address 192.168.2.2 255.255.255.0
 encapsulation ppp
```

```
R1# show interfaces serial 0/0/0
Serial0/0/0 is up, line protocol is up
  Hardware is WIC MBRD Serial
  Description: link to R2
  Internet address is 192.168.2.1/24
  MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation PPP, LCP Open
  Open: IPCP, CDPCP, loopback not set
! Lines omitted for brevity
! R1 disables keepalives, and remains in an up/up state.
R1# show interfaces s0/0/0
Serial0/0/0 is up, line protocol is up
  Hardware is WIC MBRD Serial
  Description: link to R2
  Internet address is 192.168.2.1/24
  MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation HDLC, loopback not set
  Keepalive not set
! lines omitted for brevity
```

```
! Below, R2 still has keepalives enabled (default)
R2# show interfaces S0/0/1
Serial0/0/1 is up, line protocol is down
  Hardware is WIC MBRD Serial
  Internet address is 192.168.2.2/24
  MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation HDLC, loopback not set
  Keepalive set (10 sec)
! lines omitted for brevity
```



```
R1# debug ppp authentication
PPP authentication debugging is on
R1#
*Nov 18 23:34:30.060: %LINK-3-UPDOWN: Interface Serial0/0/0, changed state to up
*Nov 18 23:34:30.060: Se0/0/0 PPP: Using default call direction
*Nov 18 23:34:30.060: Se0/0/0 PPP: Treating connection as a dedicated line
*Nov 18 23:34:30.060: Se0/0/0 PPP: Session handle[58000009] Session id[7]
*Nov 18 23:34:30.064: Se0/0/0 CHAP: O CHALLENGE id 1 len 23 from "R1"
*Nov 18 23:34:30.084: Se0/0/0 CHAP: I CHALLENGE id 1 len 23 from "R2"
*Nov 18 23:34:30.084: Se0/0/0 PPP: Sent CHAP SENDAUTH Request
*Nov 18 23:34:30.084: Se0/0/0 CHAP: I RESPONSE id 1 len 23 from "R2"
*Nov 18 23:34:30.084: Se0/0/0 PPP: Received SENDAUTH Response PASS
*Nov 18 23:34:30.084: Se0/0/0 CHAP: Using hostname from configured hostname
*Nov 18 23:34:30.084: Se0/0/0 CHAP: Using password from AAA
*Nov 18 23:34:30.084: Se0/0/0 CHAP: O RESPONSE id 1 len 23 from "R1"
*Nov 18 23:34:30.084: Se0/0/0 PPP: Sent CHAP LOGIN Request
*Nov 18 23:34:30.084: Se0/0/0 PPP: Received LOGIN Response PASS
*Nov 18 23:34:30.088: Se0/0/0 CHAP: O SUCCESS id 1 len 4
*Nov 18 23:34:30.088: Se0/0/0 CHAP: I SUCCESS id 1 len 4
```

```
R1# debug ppp authentication
PPP authentication debugging is on
! Lines omitted for brevity
*Nov 18 23:45:48.820: Se0/0/0 CHAP: O CHALLENGE id 1 len 23 from "R1"
*Nov 18 23:45:48.820: Se0/0/0 CHAP: I RESPONSE id 1 len 23 from "R2"
*Nov 18 23:45:48.820: Se0/0/0 CHAP: O FAILURE id 1 len 25 msg is "Authentication
failed"
```

```
R1# show ip route
! Legend omitted for brevity
      192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.1.0/24 is directly connected, GigabitEthernet0/0
L        192.168.1.1/32 is directly connected, GigabitEthernet0/0
      192.168.2.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.2.0/24 is directly connected, Serial0/0/0
L        192.168.2.1/32 is directly connected, Serial0/0/0
      192.168.3.0/32 is subnetted, 1 subnets
C        192.168.3.2 is directly connected, Serial0/0/0

R1# ping 192.168.3.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.3.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/2/4 ms
```

```
interface serial0/1/1
 encapsulation frame-relay
 ip address  199.1.1.1  255.255.255.0
!
interface gigabitethernet 0/0
 ip address  199.1.10.1  255.255.255.0
!
router eigrp 1
 network 199.1.1.0
 network 199.1.10.0
```

```
interface serial0/1/1
 encapsulation frame-relay
 ip address  199.1.1.2  255.255.255.0
!
interface gigabitethernet 0/0
 ip address  199.1.11.2   255.255.255.0
!
router eigrp 1
 network 199.1.1.0
 network 199.1.11.0
```

```
interface serial0/1/1
 encapsulation frame-relay
 ip address  199.1.1.3  255.255.255.0
!
interface gigabitethernet 0/0
 ip address  199.1.12.3   255.255.255.0
!
router eigrp 1
 network 199.1.1.0
 network 199.1.12.0
```

```
interface serial0/1/1
 encapsulation frame-relay
 frame-relay lmi-type ansi
 frame-relay map ip 199.1.1.3 53 ietf
 ip address 199.1.1.1  255.255.255.0
! rest of configuration unchanged from Example 14-1.
```

```
interface serial0/1/1
 encapsulation frame-relay ietf
 ip address  199.1.1.3  255.255.255.0

! rest of configuration unchanged from Example 14-3.
```

```
Mayberry# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      199.1.1.0/24 is variably subnetted, 2 subnets, 2 masks
C        199.1.1.0/24 is directly connected, Serial0/1/1
L        199.1.1.1/32 is directly connected, Serial0/1/1
      199.1.10.0/24 is variably subnetted, 2 subnets, 2 masks
C        199.1.10.0/24 is directly connected, GigabitEthernet0/0
L        199.1.10.1/32 is directly connected, GigabitEthernet0/0
D     199.1.11.0/24 [90/2172416] via 199.1.1.2, 00:00:03, Serial0/1/1
D     199.1.12.0/24 [90/2172416] via 199.1.1.3, 00:19:14, Serial0/1/1

Mayberry# show frame-relay pvc
```

```
PVC Statistics for interface Serial0/1/1 (Frame Relay DTE)

              Active     Inactive      Deleted       Static
  Local          2           0            0             0
  Switched       0           0            0             0
  Unused         0           0            0             0

DLCI = 52, DLCI USAGE = LOCAL, PVC STATUS = ACTIVE, INTERFACE = Serial0/1/1

  input pkts 37            output pkts 39           in bytes 2542
  out bytes 2752           dropped pkts 0           in pkts dropped 0
  out pkts dropped 0                out bytes dropped 0
  in FECN pkts 0           in BECN pkts 0           out FECN pkts 0
  out BECN pkts 0          in DE pkts 0             out DE pkts 0
  out bcast pkts 26        out bcast bytes 1664
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
  pvc create time 00:20:02, last time pvc status changed 00:20:02

DLCI = 53, DLCI USAGE = LOCAL, PVC STATUS = ACTIVE, INTERFACE = Serial0/1/1

  input pkts 37            output pkts 37           in bytes 2618
  out bytes 2746           dropped pkts 0           in pkts dropped 0
  out pkts dropped 0                out bytes dropped 0
  in FECN pkts 0           in BECN pkts 0           out FECN pkts 0
  out BECN pkts 0          in DE pkts 0             out DE pkts 0
  out bcast pkts 25        out bcast bytes 1630
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
  pvc create time 00:20:02, last time pvc status changed 00:20:02

Mayberry# show frame-relay map
Serial0/1/1 (up): ip 199.1.1.2 dlci 52(0x34,0xC40), dynamic,
              broadcast,, status defined, active
Serial0/1/1 (up): ip 199.1.1.3 dlci 53(0x35,0xC50), dynamic,
              broadcast,, status defined, active
```

Mayberry

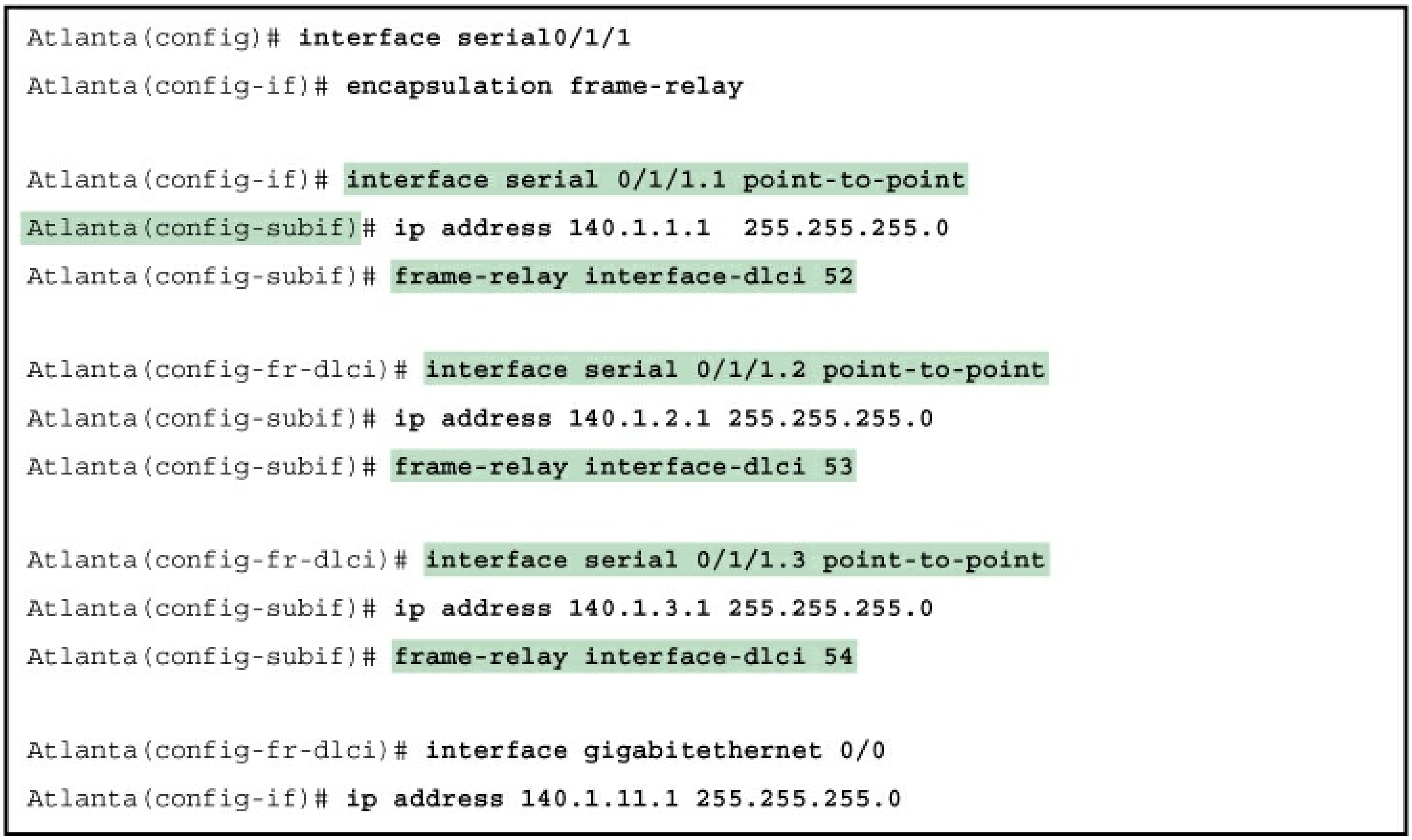
```
interface serial 0/0/0
 no frame-relay inverse-arp
 frame-relay map ip 199.1.1.2 52 broadcast
 frame-relay map ip 199.1.1.3 53 broadcast
```

Mount Pilot

```
interface serial 0/0/0
 no frame-relay inverse-arp
 frame-relay map ip 199.1.1.1 51 broadcast
 frame-relay map ip 199.1.1.3 53 broadcast
```

Raleigh

```
interface serial 0/0/0
 no frame-relay inverse-arp
 frame-relay map ip 199.1.1.1 51 broadcast
 frame-relay map ip 199.1.1.2 52 broadcast
```

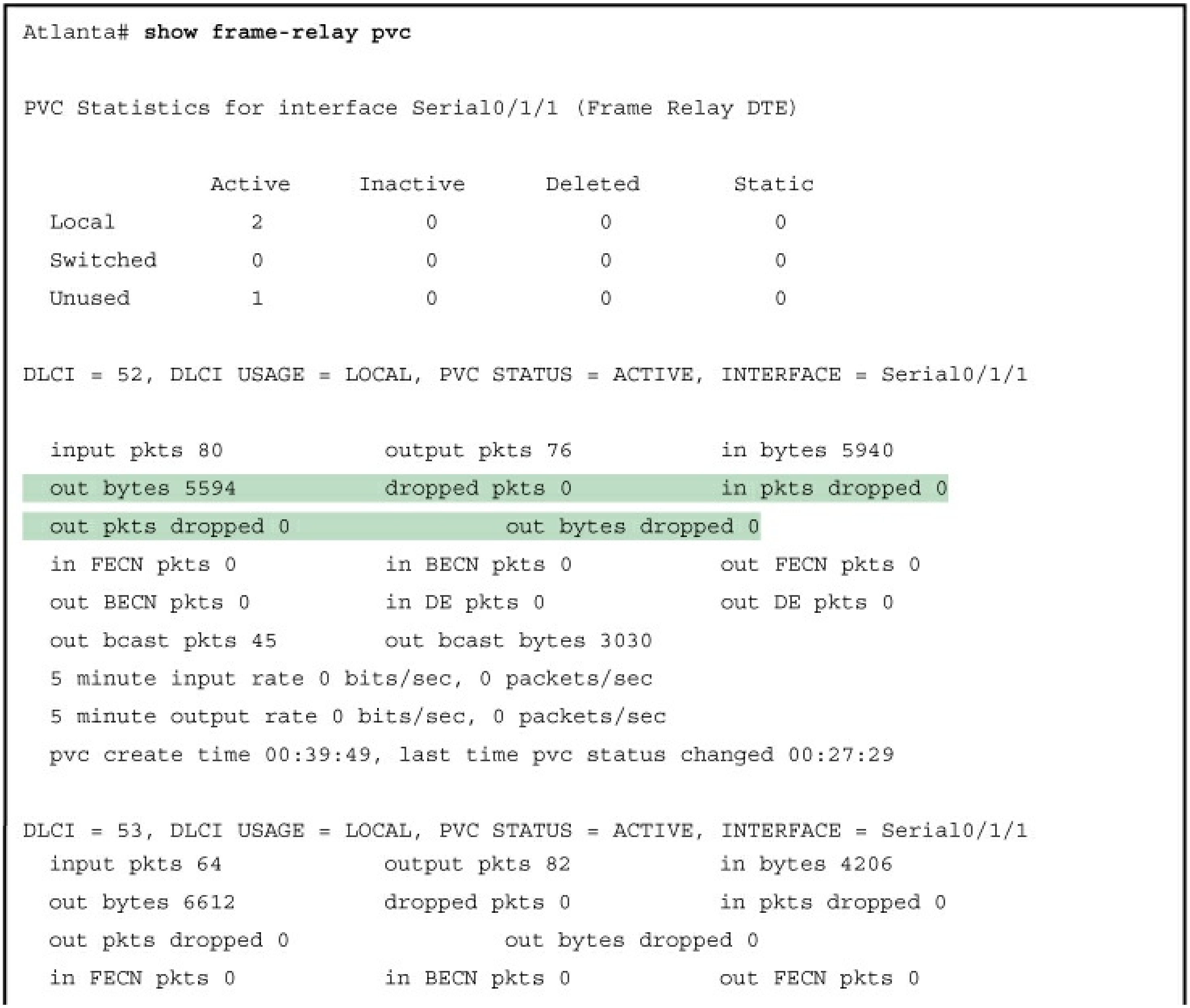


```
Atlanta(config)# interface serial0/1/1
Atlanta(config-if)# encapsulation frame-relay

Atlanta(config-if)# interface serial 0/1/1.1 point-to-point
Atlanta(config-subif)# ip address 140.1.1.1  255.255.255.0
Atlanta(config-subif)# frame-relay interface-dlci 52

Atlanta(config-fr-dlci)# interface serial 0/1/1.2 point-to-point
Atlanta(config-subif)# ip address 140.1.2.1 255.255.255.0
Atlanta(config-subif)# frame-relay interface-dlci 53

Atlanta(config-fr-dlci)# interface serial 0/1/1.3 point-to-point
Atlanta(config-subif)# ip address 140.1.3.1 255.255.255.0
Atlanta(config-subif)# frame-relay interface-dlci 54

Atlanta(config-fr-dlci)# interface gigabitethernet 0/0
Atlanta(config-if)# ip address 140.1.11.1 255.255.255.0
```

```
interface serial0/1/1
 encapsulation frame-relay
!
interface serial 0/1/1.1 point-to-point
 ip address 140.1.1.2  255.255.255.0
 frame-relay interface-dlci 51
!
interface gigabitethernet 0/0
 ip address 140.1.12.2 255.255.255.0
```

```
interface serial0/1/1
 encapsulation frame-relay
!
interface serial 0/1/1.2 point-to-point
 ip address 140.1.2.3 255.255.255.0
 frame-relay interface-dlci 51
!
interface gigabitethernet 0/0
 ip address 140.1.13.3 255.255.255.0
```

```
interface serial0/1/1
encapsulation frame-relay
!
interface serial 0/1/1.3 point-to-point
ip address 140.1.3.4 255.255.255.0
frame-relay interface-dlci 51
!
interface gigabitethernet 0/0
ip address 140.1.14.4  255.255.255.0
```

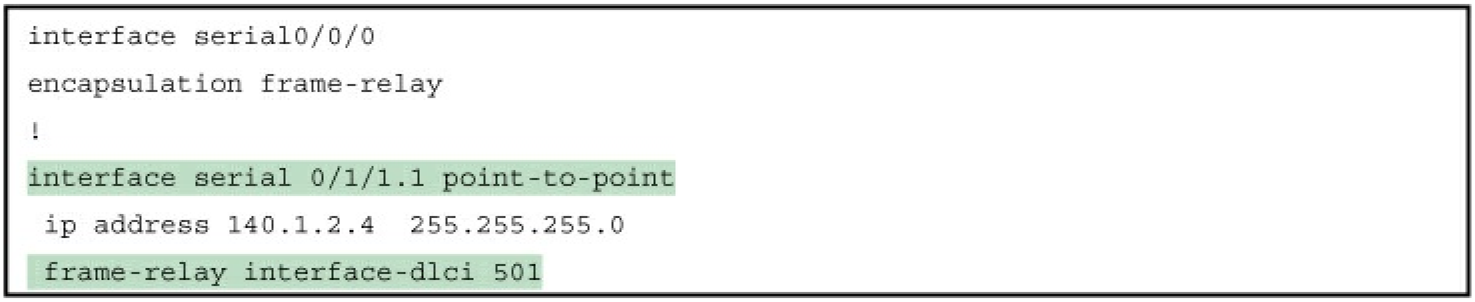


```
Atlanta# show frame-relay pvc

PVC Statistics for interface Serial0/1/1 (Frame Relay DTE)

              Active     Inactive      Deleted       Static
  Local          2            0             0            0
  Switched       0            0             0            0
  Unused         1            0             0            0

DLCI = 52, DLCI USAGE = LOCAL, PVC STATUS = ACTIVE, INTERFACE = Serial0/1/1

  input pkts 80            output pkts 76            in bytes 5940
  out bytes 5594           dropped pkts 0            in pkts dropped 0
  out pkts dropped 0                 out bytes dropped 0
  in FECN pkts 0           in BECN pkts 0            out FECN pkts 0
  out BECN pkts 0          in DE pkts 0              out DE pkts 0
  out bcast pkts 45        out bcast bytes 3030
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
  pvc create time 00:39:49, last time pvc status changed 00:27:29

DLCI = 53, DLCI USAGE = LOCAL, PVC STATUS = ACTIVE, INTERFACE = Serial0/1/1
  input pkts 64            output pkts 82            in bytes 4206
  out bytes 6612           dropped pkts 0            in pkts dropped 0
  out pkts dropped 0                 out bytes dropped 0
  in FECN pkts 0           in BECN pkts 0            out FECN pkts 0
  out BECN pkts 0          in DE pkts 0             out DE pkts 0
  out bcast pkts 38        out bcast bytes 2532
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
  pvc create time 00:33:49, last time pvc status changed 00:27:19

DLCI = 54, DLCI USAGE = UNUSED, PVC STATUS = ACTIVE, INTERFACE = Serial0/1/1

  input pkts 0             output pkts 0            in bytes 0
  out bytes 0              dropped pkts 0           in pkts dropped 0
  out pkts dropped 0                out bytes dropped 0
  in FECN pkts 0           in BECN pkts 0           out FECN pkts 0
  out BECN pkts 0          in DE pkts 0             out DE pkts 0
  out bcast pkts 0         out bcast bytes 0           5 minute input rate 0 bits/sec,
0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
  pvc create time 00:00:59, last time pvc status changed 00:00:59

Atlanta# show frame-relay map
Serial0/0/0.3 (up): point-to-point dlci, dlci 54(0x36,0xC60), broadcast
          status defined, active
Serial0/0/0.2 (up): point-to-point dlci, dlci 53(0x35,0xC50), broadcast
          status defined, active
Serial0/0/0.1 (up): point-to-point dlci, dlci 52(0x34,0xC40), broadcast
          status defined, active

Atlanta# debug frame-relay lmi
Frame Relay LMI debugging is on
Displaying all Frame Relay LMI data

Serial0/0/0(out): StEnq, myseq 163, yourseen 161, DTE up
datagramstart = 0x45AED8, datagramsize = 13
FR encap = 0xFCF10309
00 75 01 01 01 03 02 A3 A1

Serial0/0/0(in): Status, myseq 163
RT IE 1, length 1, type 1
KA IE 3, length 2, yourseq 162, myseq 163
```

```
interface serial0/1/1
 encapsulation frame-relay
!
interface serial 0/1/1.1 multipoint
 ip address 140.1.1.1  255.255.255.0
 frame-relay interface-dlci 502
 frame-relay interface-dlci 503
!
interface serial 0/1/1.2 point-to-point
 ip address 140.1.2.1 255.255.255.0
 frame-relay interface-dlci 504
!
interface serial 0/1/1.3 point-to-point
 ip address 140.1.3.1 255.255.255.0
 frame-relay interface-dlci 505
```

```
interface serial0/1/1
 encapsulation frame-relay
!
interface serial 0/1/1.1 multipoint
 ip address 140.1.1.2  255.255.255.0
 frame-relay interface-dlci 501
 frame-relay interface-dlci 503
```

```
interface serial0/1/1
 encapsulation frame-relay
!
interface serial 0/1/1.1 multipoint
 ip address 140.1.1.3  255.255.255.0
 frame-relay interface-dlci 501
 frame-relay interface-dlci 502
```



```
interface serial0/0/0
encapsulation frame-relay
!
interface serial 0/1/1.1 point-to-point
 ip address 140.1.2.4  255.255.255.0
 frame-relay interface-dlci 501
```

```
interface serial0/0/0
 encapsulation frame-relay
!
interface serial 0/1/1.1 point-to-point
 ip address 140.1.3.5 255.255.255.0
 frame-relay interface-dlci 501
```

```
RouterC# show frame-relay map
Serial0/1/1.1 (up): ip 140.1.1.1 dlci 501(0x1F5,0x7C50), dynamic,
              broadcast,, status defined, active
Serial0/1/1.1 (up): ip 140.1.1.2 dlci 502(0x1F6,0x7C60), dynamic,
              broadcast,, status defined, active
```

```
R1# show frame-relay lmi


LMI Statistics for interface Serial0/0/0 (Frame Relay DTE) LMI TYPE = ANSI
  Invalid Unnumbered info 0             Invalid Prot Disc 0
  Invalid dummy Call Ref 0              Invalid Msg Type 0
  Invalid Status Message 0              Invalid Lock Shift 0
  Invalid Information ID 0              Invalid Report IE Len 0
  Invalid Report Request 0              Invalid Keep IE Len 0
  Num Status Enq. Sent 122              Num Status msgs Rcvd 34
  Num Update Status Rcvd 0              Num Status Timeouts 88
  Last Full Status Req 00:00:04         Last Full Status Rcvd 00:13:24
```

```
R1> show ip interface brief
Interface              IP-Address      OK? Method Status                Protocol
FastEthernet0/0        10.1.11.1       YES NVRAM  up                    up
FastEthernet0/1        unassigned      YES NVRAM  administratively down down
Serial0/0/0            unassigned      YES NVRAM  up                    up
Serial0/0/0.2          10.1.2.1        YES NVRAM  down                  down
Serial0/0/0.5          10.1.5.1        YES manual down                  down
Serial0/0/0.34         10.1.34.1       YES NVRAM  up                    up

R1# show interfaces s 0/0/0.2
Serial0/0/0.2 is down, line protocol is down
  Hardware is GT96K Serial
  Internet address is 10.1.2.1/24
  MTU 1500 bytes, BW 1544 Kbit, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation FRAME-RELAY
  Last clearing of "show interface" counters never
! Lines omitted for brevity
```

```
R1> show frame-relay pvc

PVC Statistics for interface Serial0/0/0 (Frame Relay DTE)

              Active     Inactive      Deleted       Static
  Local          1           2            0             0
  Switched       0           0            0             0
  Unused         0           0            0             0

DLCI = 102, DLCI USAGE = LOCAL, PVC STATUS = INACTIVE, INTERFACE = Serial0/0/0.2

  input pkts 33            output pkts 338          in bytes 1952
  out bytes 29018          dropped pkts 0           in pkts dropped 0
  out pkts dropped 0                out bytes dropped 0
  in FECN pkts 0           in BECN pkts 0           out FECN pkts 0
  out BECN pkts 0          in DE pkts 0             out DE pkts 0
  out bcast pkts 332       out bcast bytes 28614
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
  pvc create time 00:30:05, last time pvc status changed 00:04:14

DLCI = 103, DLCI USAGE = LOCAL, PVC STATUS = INACTIVE, INTERFACE = Serial0/0/0.34

  input pkts 17            output pkts 24           in bytes 1106
  out bytes 2086           dropped pkts 0           in pkts dropped 0
  out pkts dropped 0                out bytes dropped 0
  in FECN pkts 0           in BECN pkts 0           out FECN pkts 0
  out BECN pkts 0          in DE pkts 0             out DE pkts 0
  out bcast pkts 11        out bcast bytes 674
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
  pvc create time 00:30:07, last time pvc status changed 00:02:57

DLCI = 104, DLCI USAGE = LOCAL, PVC STATUS = ACTIVE, INTERFACE = Serial0/0/0.34

  input pkts 41            output pkts 42           in bytes 2466
  out bytes 3017           dropped pkts 0           in pkts dropped 0
  out pkts dropped 0                out bytes dropped 0
  in FECN pkts 0           in BECN pkts 0           out FECN pkts 0
  out BECN pkts 0          in DE pkts 0             out DE pkts 0
  out bcast pkts 30        out bcast bytes 1929
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
  pvc create time 00:30:07, last time pvc status changed 00:26:17
```

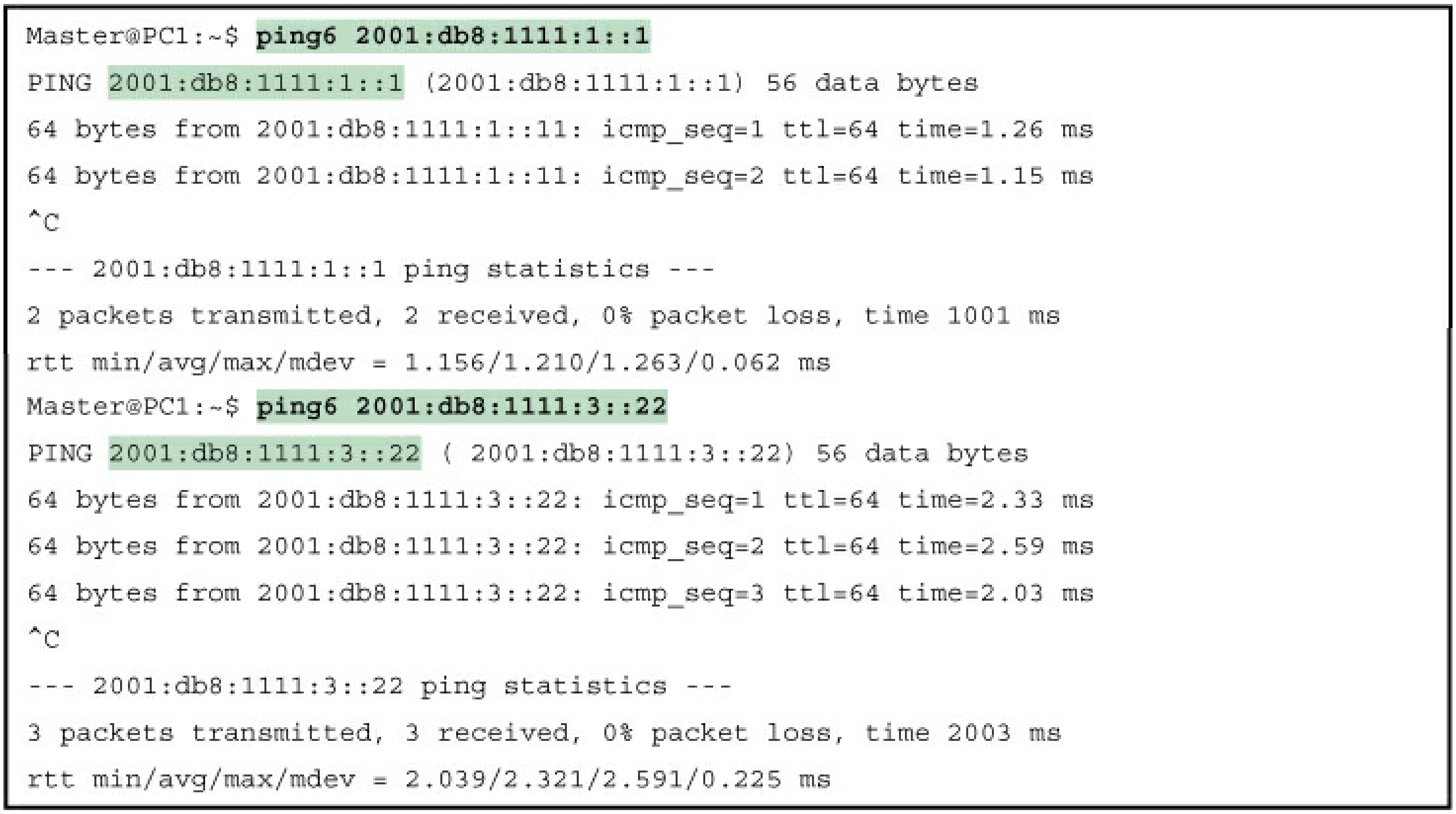
```
R1> show frame-relay pvc 102

PVC Statistics for interface Serial0/0/0 (Frame Relay DTE)

DLCI = 102, DLCI USAGE = LOCAL, PVC STATUS = INACTIVE, INTERFACE = Serial0/0/0.2

  input pkts 22            output pkts 193          in bytes 1256
  out bytes 16436          dropped pkts 0           in pkts dropped 0
  out pkts dropped 0                out bytes dropped 0
  in FECN pkts 0           in BECN pkts 0           out FECN pkts 0
  out BECN pkts 0          in DE pkts 0             out DE pkts 0
  out bcast pkts 187       out bcast bytes 16032
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
  pvc create time 01:12:56, last time pvc status changed 00:22:45
```

```
R1# show frame-relay map
Serial0/0/0.34 (up): ip 10.1.34.4 dlci 104(0x68,0x1880), static,
              broadcast,
              CISCO, status defined, active
Serial0/0/0.34 (up): ip 10.1.34.3 dlci 103(0x67,0x1870), dynamic,
              broadcast,, status defined, active
Serial0/0/0.2 (up): point-to-point dlci, dlci 102(0x66,0x1860), broadcast
          status defined, active
```

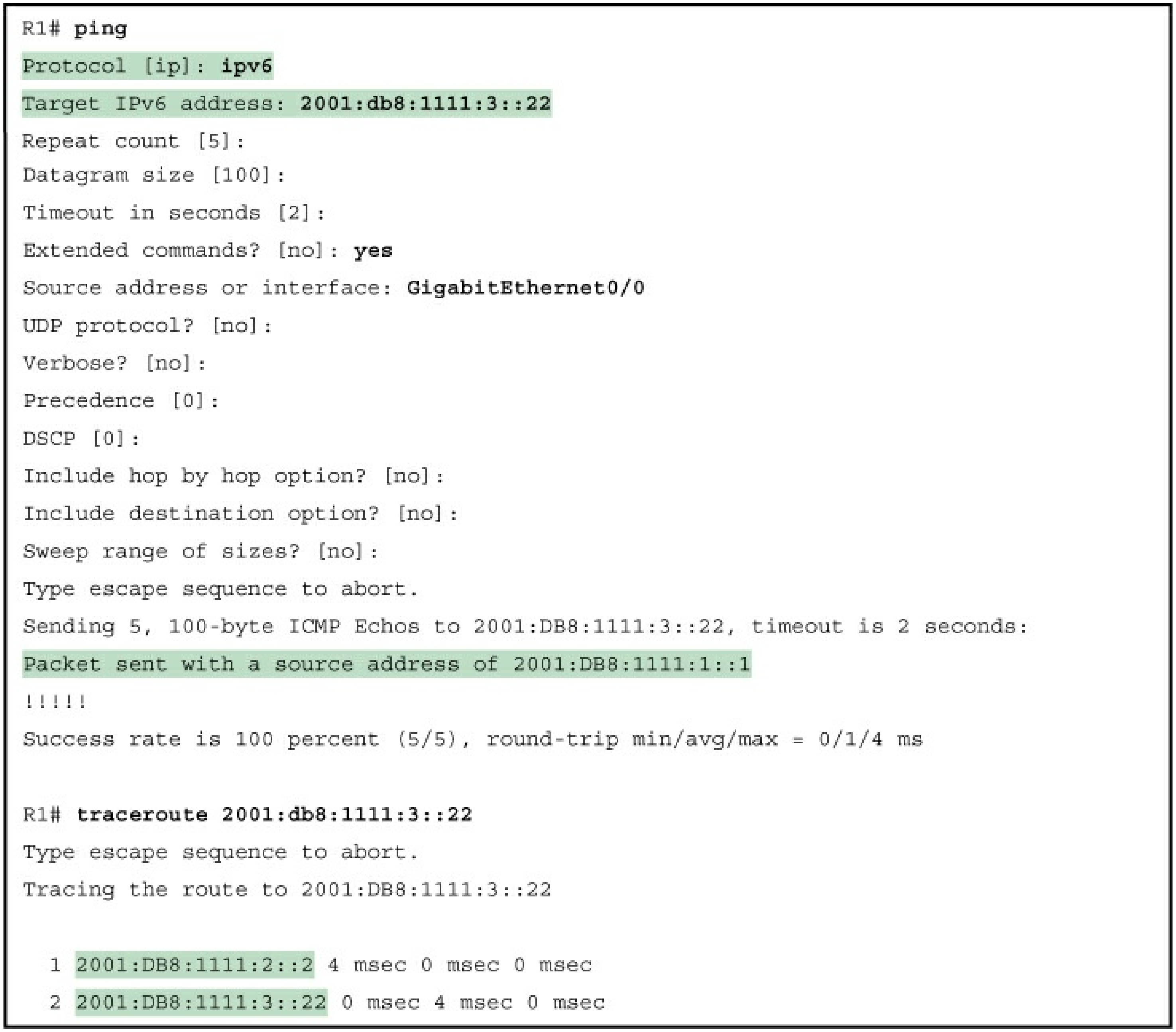
```
ipv6 unicast-routing
!
interface serial0/0/1
  ipv6 address 2001:db8:1111:2::1/64
!
interface gigabitethernet0/0
  ipv6 address 2001:db8:1111:1::1/64
!
interface gigabitethernet0/1
  ipv6 address 2001:db8:1111:4::1/64
```

```
! The next command uses R1's S0/0/1 as the outgoing interface
ipv6 route 2001:db8:1111:3::/64 S0/0/1

! The next command uses R2's address as the next-hop router unicast address
ipv6 route 2001:db8:1111:3::/64 2001:DB8:1111:2::2

! The next command uses R1's S0/0/1 as the outgoing interface, and
! R2's link-local address as the next-hop router address
ipv6 route 2001:db8:1111:3::/64 S0/0/1 FE80::FF:FE00:2
```

```
WOair$ ifconfig en0
eth0: Link encap:Ethernet  Hwaddr 02:00:11:11:11:11
      inet addr:10.1.1.99  Bcast:10.1.1.255  Mask:255.255.255.0
      inet6 addr: fe80::11ff:fe11:1111/64 Scope:Link
      inet6 2001:db8:1111:1::11/64 Scope:Global
      UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
      RX packets: 45 errors:0 droppped:0 overruns:0 frame:0
      TX packets: 804 errors:0 droppped:0 overruns:0 carrier:0
      collisions:0 txqueuelen:1000
      RX bytes:5110 (5.1 KB)  TX bytes:140120 (140.1 KB)
```



```
Master@PC1:~$ ping6 2001:db8:1111:1::1
PING 2001:db8:1111:1::1 (2001:db8:1111:1::1) 56 data bytes
64 bytes from 2001:db8:1111:1::11: icmp_seq=1 ttl=64 time=1.26 ms
64 bytes from 2001:db8:1111:1::11: icmp_seq=2 ttl=64 time=1.15 ms
^C
--- 2001:db8:1111:1::1 ping statistics ---
2 packets transmitted, 2 received, 0% packet loss, time 1001 ms
rtt min/avg/max/mdev = 1.156/1.210/1.263/0.062 ms
Master@PC1:~$ ping6 2001:db8:1111:3::22
PING 2001:db8:1111:3::22 ( 2001:db8:1111:3::22) 56 data bytes
64 bytes from 2001:db8:1111:3::22: icmp_seq=1 ttl=64 time=2.33 ms
64 bytes from 2001:db8:1111:3::22: icmp_seq=2 ttl=64 time=2.59 ms
64 bytes from 2001:db8:1111:3::22: icmp_seq=3 ttl=64 time=2.03 ms
^C
--- 2001:db8:1111:3::22 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2003 ms
rtt min/avg/max/mdev = 2.039/2.321/2.591/0.225 ms
```



```
R1# ping
Protocol [ip]: ipv6
Target IPv6 address: 2001:db8:1111:3::22
Repeat count [5]:
Datagram size [100]:
Timeout in seconds [2]:
Extended commands? [no]: yes
Source address or interface: GigabitEthernet0/0
UDP protocol? [no]:
Verbose? [no]:
Precedence [0]:
DSCP [0]:
Include hop by hop option? [no]:
Include destination option? [no]:
Sweep range of sizes? [no]:
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 2001:DB8:1111:3::22, timeout is 2 seconds:
Packet sent with a source address of 2001:DB8:1111:1::1
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 0/1/4 ms

R1# traceroute 2001:db8:1111:3::22
Type escape sequence to abort.
Tracing the route to 2001:DB8:1111:3::22

  1 2001:DB8:1111:2::2 4 msec 0 msec 0 msec
  2 2001:DB8:1111:3::22 0 msec 4 msec 0 msec
```

```
R1# show ipv6 route 2001:db8:1111:3::22
Routing entry for 2001:DB8:1111:3::/64
  Known via "static", distance 1, metric 0
  Route count is 1/1, share count 0
  Routing paths:
    directly connected via Serial0/0/1
      Last updated 00:01:29 ago

R1# show ipv6 route 2001:1:1:1::1
% Route not found
```

```
R2# show ipv6 neighbors
IPv6 Address                              Age Link-layer Addr State Interface
FE80::11FF:FE11:1111                        0 0200.1111.1111  STALE Gi0/0
FE80::22FF:FE22:2222                        1 0200.2222.2222  STALE Gi0/0
2001:DB8:1111:3::22                         0 0200.2222.2222  REACH Gi0/0
FE80::D68C:B5FF:FE7D:8200                   1 d48c.b57d.8200  DELAY Gi0/0
2001:DB8:1111:3::33                         0 0200.1111.1111  REACH Gi0/0
2001:DB8:1111:3::3                          0 d48c.b57d.8200  REACH Gi0/0
```

```
R2# show ipv6 interface
Serial0/0/0 is up, line protocol is up
  IPv6 is enabled, link-local address is FE80::FF:FE00:1
  No Virtual link-local address(es):
  Global unicast address(es):
    2001:DB8:1:12::1, subnet is 2001:DB8:1:12::/64
  Joined group address(es):
    FF02::1
    FF02::2
    FF02::5
    FF02::1:FF00:1
  MTU is 1500 bytes
  ICMP error messages limited to one every 100 milliseconds
  ICMP redirects are enabled
  ICMP unreachables are sent
  Output features: Access List
  Outgoing access list book
! Lines omitted for brevity
```

```
ipv6 unicast-routing
!
interface GigabitEthernet0/0
 mac-address 0200.0000.0002
 ipv6 address 2001:db8:1:23::2/64
 ipv6 ospf 2 area 23
!
interface serial 0/0/1
 ipv6 address 2001:db8:1:12::2/64
 ipv6 ospf 2 area 23
!
ipv6 router ospf 2
 router-id 2.2.2.2
```

```
ipv6 unicast-routing
!
interface GigabitEthernet0/0
 mac-address 0200.0000.0003
 ipv6 address 2001:db8:1:23::3/64
 ipv6 ospf 3 area 23
!
interface serial 0/0/0
 ipv6 address 2001:db8:1:13::3/64
 ipv6 ospf 3 area 23
!
ipv6 router ospf 3
 router-id 3.3.3.3
```

```
ipv6 unicast-routing
!
interface GigabitEthernet0/0
 mac-address 0200.0000.0004
 ipv6 address 2001:db8:1:14::4/64
 ipv6 ospf 4 area 4
!
interface GigabitEthernet0/1
 ipv6 address 2001:db8:1:4::4/64
 ipv6 ospf 4 area 4
!
ipv6 router ospf 4
 router-id 4.4.4.4
 passive-interface gigabitethernet0/1
```

```
ipv6 unicast-routing
!
interface GigabitEthernet0/0
 mac-address 0200.0000.0001
!
interface GigabitEthernet0/0.11
 encapsulation dot1q 11
 ipv6 address 2001:db8:1:1::1/64
 ipv6 ospf 1 area 0
!
interface GigabitEthernet0/0.12
 encapsulation dot1q 12
 ipv6 address 2001:db8:1:2::1/64
 ipv6 ospf 1 area 0
!
interface GigabitEthernet0/1
 ipv6 address 2001:db8:1:14::1/64
 ipv6 ospf 1 area 4
!
interface serial 0/0/0
 ipv6 address 2001:db8:1:12::1/64
 ipv6 ospf 1 area 23
!
interface serial 0/0/1
 ipv6 address 2001:db8:1:13::1/64
 ipv6 ospf 1 area 23
!
ipv6 router ospf 1
 router-id 1.1.1.1
```

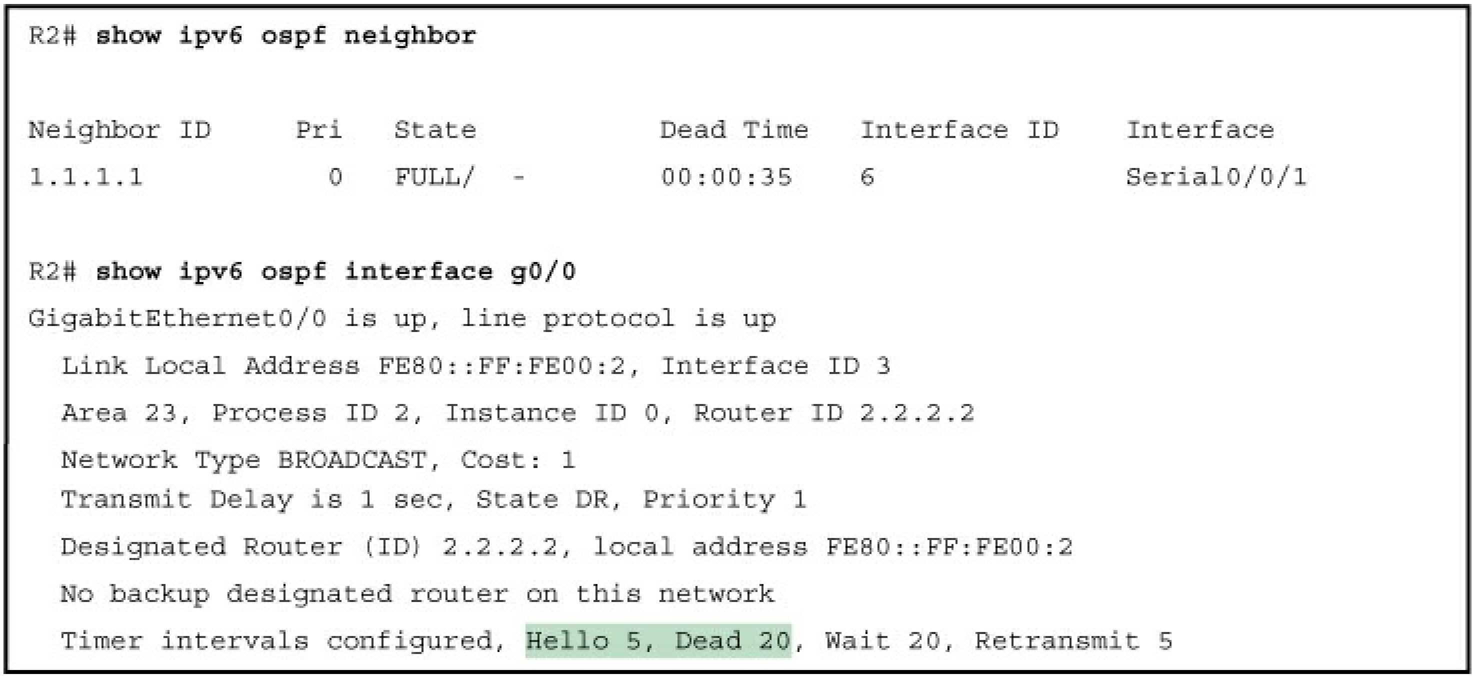
```
R1# show ipv6 protocols
IPv6 Routing Protocol is "connected"
IPv6 Routing Protocol is "ND"
IPv6 Routing Protocol is "ospf 1"
  Interfaces (Area 0):
    GigabitEthernet0/0.12
    GigabitEthernet0/0.11
  Interfaces (Area 4):
    GigabitEthernet0/1
  Interfaces (Area 23):
    Serial0/0/1
    Serial0/0/0
  Redistribution:
    None
```

```
R1# show ipv6 ospf interface brief
Interface    PID   Area            Intf ID    Cost  State Nbrs F/C
Gi0/0.12     1     0               16         1     DR    0/0
Gi0/0.11     1     0               17         1     DR    0/0
Gi0/1        1     4               4          1     DR    1/1
Se0/0/1      1     23              7          64    P2P   1/1
Se0/0/0      1     23              6          64    P2P   1/1

R1# show ipv6 ospf interface G0/0.11
GigabitEthernet0/0.11 is up, line protocol is up
  Link Local Address FE80::FF:FE00:1, Interface ID 17
  Area 0, Process ID 1, Instance ID 0, Router ID 1.1.1.1
  Network Type BROADCAST, Cost: 1
  Transmit Delay is 1 sec, State DR, Priority 1
  Designated Router (ID) 1.1.1.1, local address FE80::FF:FE00:1
  No backup designated router on this network
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    No Hellos (Passive interface)
! remaining lines omitted for brevity
```

```
R4# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R4(config)# ipv6 router ospf 4
R4(config-rtr)# passive-interface gigabitEthernet 0/0
R4(config-rtr)# ^Z
R4#
Jan 17 23:49:56.379: %OSPFv3-5-ADJCHG: Process 4, Nbr 1.1.1.1 on GigabitEthernet0/0
from FULL to DOWN, Neighbor Down: Interface down or detached
```

```
R2# debug ipv6 ospf adj
R2#
Jan 15 14:50:58.098: OSPFv3-2-IPv6 ADJ   Gi0/0: Added 3.3.3.3 to nbr list
Jan 15 14:50:58.098: OSPFv3-2-IPv6 ADJ   Gi0/0: 2 Way Communication to 3.3.3.3, state
2WAY
Jan 15 14:50:58.098: OSPFv3-2-IPv6 ADJ   Gi0/0:  DR: 3.3.3.3 (Id)   BDR: 2.2.2.2 (Id)
Jan 15 14:50:58.098: OSPFv3-2-IPv6 ADJ   Gi0/0: Nbr 3.3.3.3: Prepare dbase exchange
Jan 15 14:50:58.098: OSPFv3-2-IPv6 ADJ   Gi0/0: Send DBD to 3.3.3.3 seq 0x2AC5B307 opt
0x0013 flag 0x7 len 28
Jan 15 14:50:58.102: OSPFv3-2-IPv6 ADJ   Gi0/0: Rcv DBD from 3.3.3.3 seq 0xBD091ED opt
0x0013 flag 0x7 len 28  mtu 1500 state EXSTART
Jan 15 14:50:58.102: OSPFv3-2-IPv6 ADJ   Gi0/0: NBR Negotiation Done. We are the SLAVE
Jan 15 14:50:58.102: OSPFv3-2-IPv6 ADJ   Gi0/0: Nbr 3.3.3.3: Summary list built, size
14
Jan 15 14:50:58.106: OSPFv3-2-IPv6 ADJ   Gi0/0: Rcv DBD from 3.3.3.3 seq 0xBD091EE opt
0x0013 flag 0x1 len 308  mtu 1500 state EXCHANGE
Jan 15 14:50:58.106: OSPFv3-2-IPv6 ADJ   Gi0/0: Exchange Done with 3.3.3.3
Jan 15 14:50:58.106: OSPFv3-2-IPv6 ADJ   Gi0/0: Synchronized with 3.3.3.3, state FULL
Jan 15 14:50:58.106: %OSPFv3-5-ADJCHG: Process 2, Nbr 3.3.3.3 on GigabitEthernet0/0
from LOADING to FULL, Loading Done

R2# show ipv6 ospf neighbors

Neighbor ID     Pri   State           Dead Time   Interface ID    Interface
1.1.1.1           0   FULL/  -        00:00:38    6               Serial0/0/1
3.3.3.3           1   FULL/DR         00:00:37    3               GigabitEthernet0/0
```

```
R4# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R4(config)# ipv6 router ospf 4
R4(config-rtr)# router-id 1.1.1.1
% OSPFv3: Reload or use "clear ipv6 ospf process" command, for this to take effect
R4(config-rtr)# ^Z

R4# clear ipv6 ospf process
Reset ALL OSPF processes? [no]: yes
R4#
Jan 17 23:22:03.211: %OSPFv3-5-ADJCHG: Process 4, Nbr 1.1.1.1 on GigabitEthernet0/0
from FULL to DOWN, Neighbor Down: Interface down or detached
R4#
Jan 17 23:22:05.635: %OSPFv3-4-DUP_RTRID_NBR: OSPF detected duplicate router-id
1.1.1.1 from FE80::604:5FF:FE05:707 on interface GigabitEthernet0/0
R4#
R4# show ipv6 ospf neighbor
R4#
```



```
R2# show ipv6 ospf neighbor

Neighbor ID     Pri   State           Dead Time   Interface ID    Interface
1.1.1.1           0   FULL/  -        00:00:35    6               Serial0/0/1

R2# show ipv6 ospf interface g0/0
GigabitEthernet0/0 is up, line protocol is up
  Link Local Address FE80::FF:FE00:2, Interface ID 3
  Area 23, Process ID 2, Instance ID 0, Router ID 2.2.2.2
  Network Type BROADCAST, Cost: 1
  Transmit Delay is 1 sec, State DR, Priority 1
  Designated Router (ID) 2.2.2.2, local address FE80::FF:FE00:2
  No backup designated router on this network
  Timer intervals configured, Hello 5, Dead 20, Wait 20, Retransmit 5
```

```
R4# show ipv6 ospf database

            OSPFv3 Router with ID (4.4.4.4) (Process ID 4)

                Router Link States (Area 4)


ADV Router      Age         Seq#        Fragment ID  Link count  Bits
 1.1.1.1        258         0x80000072  0            1           B
 4.4.4.4        257         0x80000003  0            1           None

                Net Link States (Area 4)
ADV Router      Age         Seq#        Link ID    Rtr count
 4.4.4.4        257         0x80000001  4          2

                Inter Area Prefix Link States (Area 4)


ADV Router      Age         Seq#       Prefix
 1.1.1.1        878         0x80000069  2001:DB8:1:1::/64
 1.1.1.1        878         0x80000068  2001:DB8:1:2::/64
 1.1.1.1        364         0x8000000A  2001:DB8:1:13::/64
 1.1.1.1        364         0x8000000A  2001:DB8:1:23::/64
 1.1.1.1        364         0x8000000A  2001:DB8:1:12::/64


! Lines omitted for brevity
```

```
R4# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R4(config)# interface gigabitethernet0/0
R4(config-if)# ipv6 mtu 1400
R4(config-if)# ^Z
R4#
R4# clear ipv6 ospf 4 process
Reset OSPF process? [no]: yes
R4#
Jan 17 23:53:24.439: %OSPFv3-5-ADJCHG: Process 4, Nbr 1.1.1.1 on GigabitEthernet0/0
from FULL to DOWN, Neighbor Down: Interface down or detached


R4# show ipv6 ospf neighbor


Neighbor ID     Pri   State           Dead Time   Interface ID    Interface
1.1.1.1           1   EXSTART/DR      00:00:37    4               GigabitEthernet0/0


Jan 17 23:55:29.063: %OSPFv3-5-ADJCHG: Process 4, Nbr 1.1.1.1 on GigabitEthernet0/0
from EXSTART to DOWN, Neighbor Down: Too many retransmits
R4# show ipv6 ospf neighbor


Neighbor ID     Pri   State           Dead Time   Interface ID    Interface
1.1.1.1           1   DOWN/DROTHER       -        4               GigabitEthernet0/0
```

```
R1# show ipv6 route ospf
! Legend omitted for brevity

O   2001:DB8:1:4::/64 [110/1]
     via GigabitEthernet0/1, directly connected
O   2001:DB8:1:23::/64 [110/65]
     via FE80::FF:FE00:3, Serial0/0/1
     via FE80::FF:FE00:2, Serial0/0/0
```

```
R2# show ipv6 route ospf
! Legend omitted for brevity
OI  2001:DB8:1:1::/64 [110/65]
     via FE80::FF:FE00:1, Serial0/0/1
OI  2001:DB8:1:2::/64 [110/65]
     via FE80::FF:FE00:1, Serial0/0/1
OI  2001:DB8:1:4::/64 [110/65]
     via FE80::FF:FE00:1, Serial0/0/1
O   2001:DB8:1:13::/64 [110/65]
     via FE80::FF:FE00:3, GigabitEthernet0/0
OI  2001:DB8:1:14::/64 [110/65]
     via FE80::FF:FE00:1, Serial0/0/1
```

```
R1# show ipv6 ospf interface brief
Interface    PID   Area            Intf ID    Cost  State Nbrs F/C
Gi0/0.12     1     0               16         1     DR    0/0
Gi0/0.11     1     0               17         1     DR    0/0
Gi0/1        1     4               4          1     BDR   1/1
Se0/0/0      1     23              6          64    P2P   1/1
Se0/0/1      1     23              7          64    P2P   1/1
```

```
R2# show ipv6 eigrp neighbors
EIGRP-IPv6 Neighbors for AS(1)
H   Address              Interface     Hold Uptime   SRTT   RTO  Q  Seq
                                       (sec)         (ms)       Cnt Num
0   Link-local address:  Gi0/0         11 06:46:11      1    100  0  30
    FE80::FF:FE22.2222
```

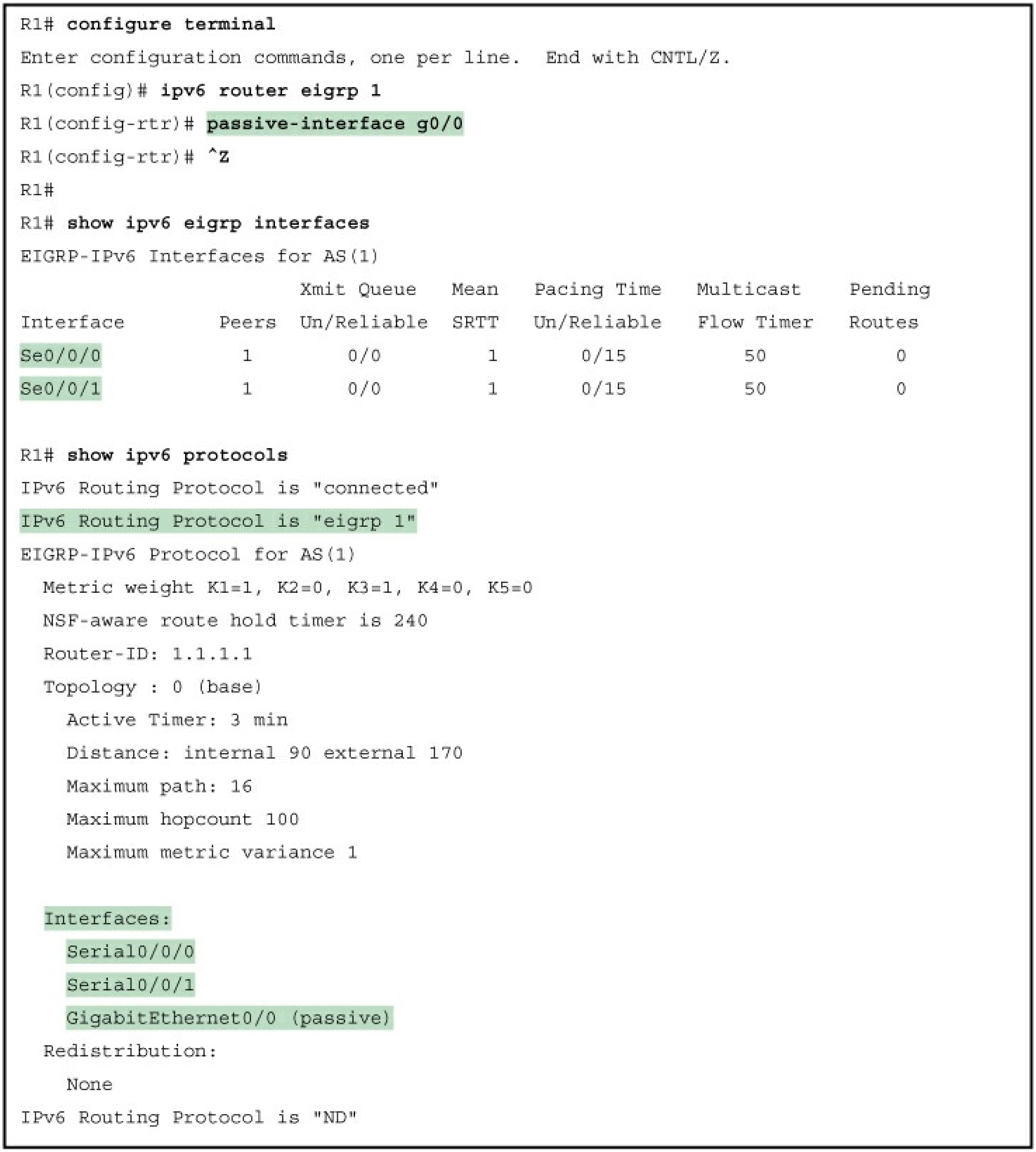
```
ipv6 unicast-routing
!
ipv6 router eigrp 1
 eigrp router-id 1.1.1.1
!
interface GigabitEthernet0/0
 ipv6 address 2001:db8:1:1::1/64
 ipv6 eigrp 1
!
interface serial 0/0/0
 description link to R2
 ipv6 address 2001:db8:1:5::1/64
 ipv6 eigrp 1
!
interface serial 0/0/1
 description link to R3
 ipv6 address 2001:db8:1:4::1/64
 ipv6 eigrp 1
```

```
ipv6 unicast-routing
!
ipv6 router eigrp 1
 eigrp router-id 2.2.2.2
!
interface GigabitEthernet0/0
 ipv6 address 2001:db8:1:2::2/64
 ipv6 eigrp 1
!
interface serial 0/0/0
 description link to R3
 ipv6 address 2001:db8:1:6::2/64
 ipv6 eigrp 1
!
interface serial 0/0/1
 description link to R1
 ipv6 address 2001:db8:1:5::2/64
 ipv6 eigrp 1
!
interface serial 0/1/0
 description link to R4
 ipv6 address 2001:db8:1:8::2/64
 ipv6 eigrp 1
```

```
R1# show ip route | section 10.1.33.0
D        10.1.33.0/24 [90/2684416] via 10.1.5.2, 00:02:23, Serial0/0/0
                      [90/2684416] via 10.1.4.3, 00:02:23, Serial0/0/1

R1# show ipv6 route | section 2001:DB8:1:33::/64
D   2001:DB8:1:33::/64 [90/2684416]
     via FE80::FF:FE00:3, Serial0/0/1
     via FE80::FF:FE00:2, Serial0/0/0
```

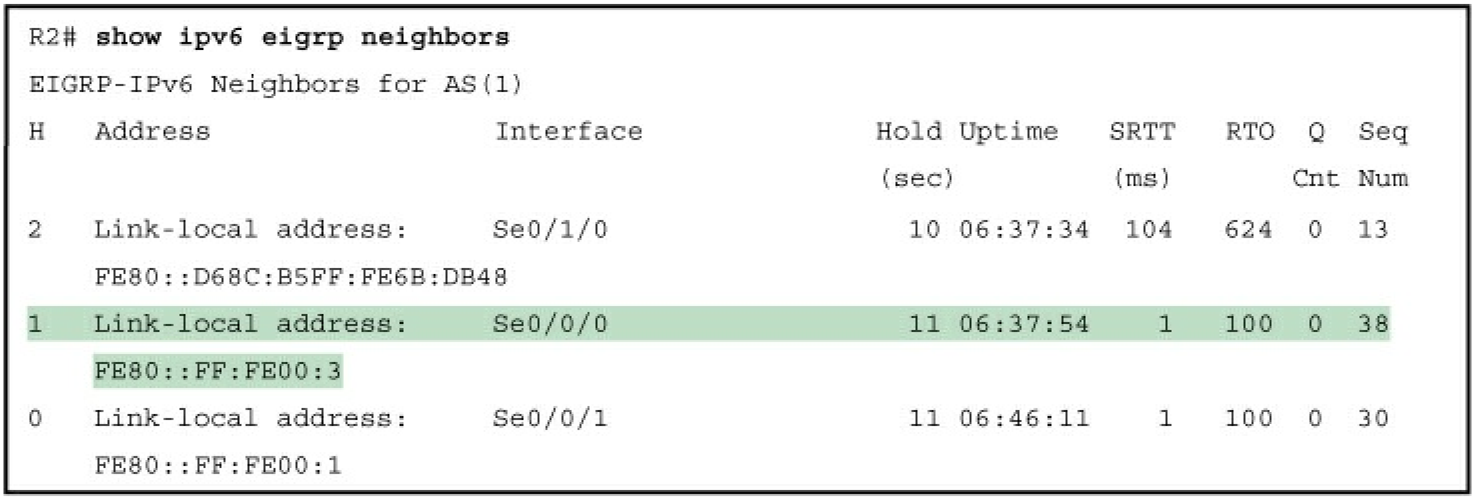
```
R1# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
! First, configure the settings for IPv4
R1(config)# router eigrp 10
R1(config-router)# maximum-paths 2
R1(config-router)# variance 3
! Next, configure the similar settings for IPv6
R1(config-router)# ipv6 router eigrp 11
R1(config-rtr)# maximum-paths 5
R1(config-rtr)# variance 4
R1(config-rtr)# ^Z
R1#
```

```
R1# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R1(config)# interface gigabitethernet0/1
R1(config-if)# ip hello-interval eigrp 10 6
R1(config-if)# ipv6 hello-interval eigrp 11 7
R1(config-rtr)# ^Z
R1#
```



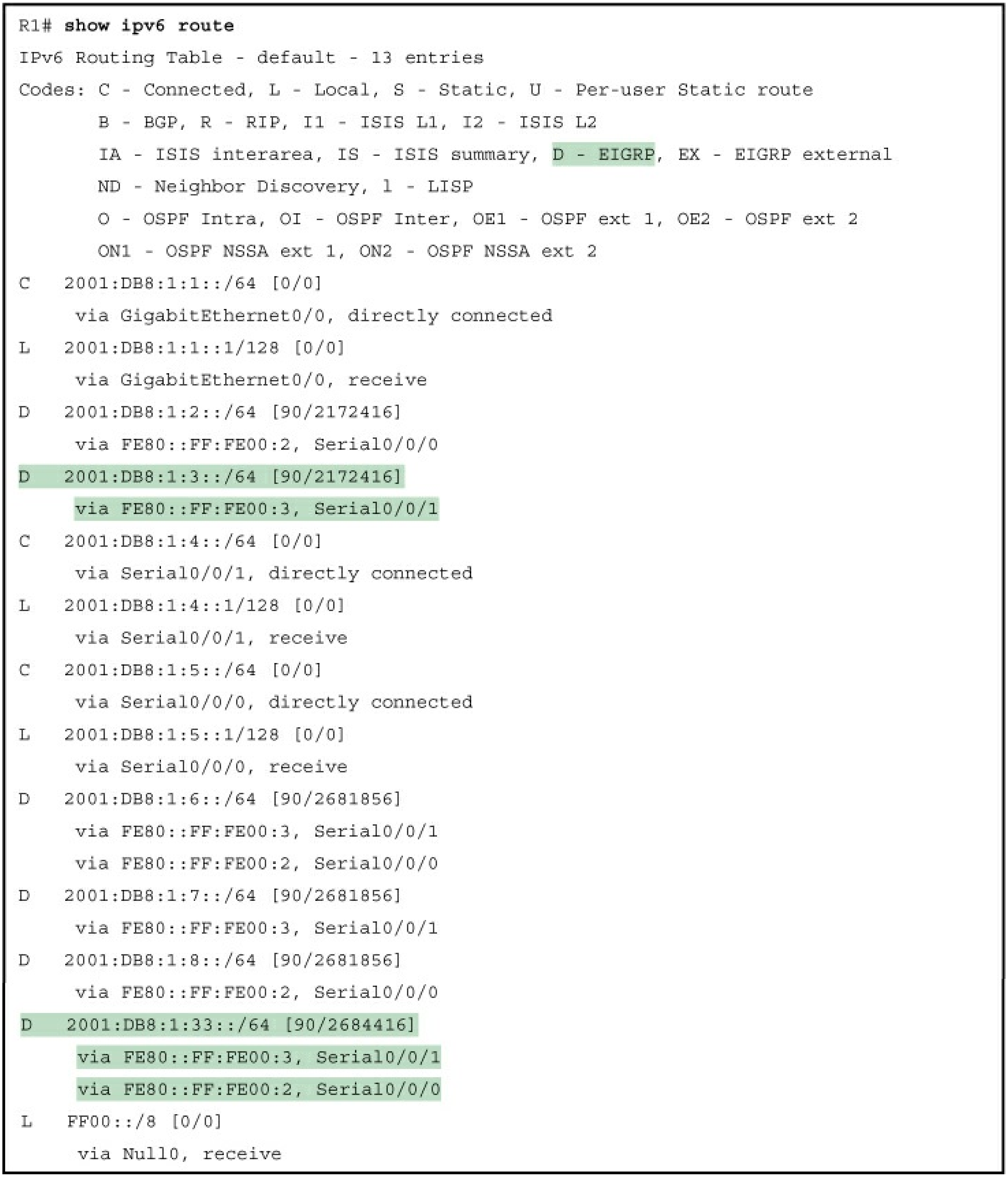
```
R1# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R1(config)# ipv6 router eigrp 1
R1(config-rtr)# passive-interface g0/0
R1(config-rtr)# ^Z
R1#
R1# show ipv6 eigrp interfaces
EIGRP-IPv6 Interfaces for AS(1)
                        Xmit Queue   Mean   Pacing Time   Multicast    Pending
Interface        Peers  Un/Reliable  SRTT   Un/Reliable   Flow Timer   Routes
Se0/0/0            1        0/0         1       0/15          50           0
Se0/0/1            1        0/0         1       0/15          50           0

R1# show ipv6 protocols
IPv6 Routing Protocol is "connected"
IPv6 Routing Protocol is "eigrp 1"
EIGRP-IPv6 Protocol for AS(1)
  Metric weight K1=1, K2=0, K3=1, K4=0, K5=0
  NSF-aware route hold timer is 240
  Router-ID: 1.1.1.1
  Topology : 0 (base)
    Active Timer: 3 min
    Distance: internal 90 external 170
    Maximum path: 16
    Maximum hopcount 100
    Maximum metric variance 1

  Interfaces:
    Serial0/0/0
    Serial0/0/1
    GigabitEthernet0/0 (passive)
  Redistribution:
    None
IPv6 Routing Protocol is "ND"
```

```
R1# show ipv6 route 2001:DB8:1:33::
% Route not found

R1# show ipv6 eigrp topology | include 2001:DB8:1:33
R1#
```



```
R2# show ipv6 eigrp neighbors
EIGRP-IPv6 Neighbors for AS(1)
H   Address                  Interface              Hold Uptime     SRTT    RTO  Q   Seq
                                                    (sec)           (ms)         Cnt Num
2   Link-local address:      Se0/1/0                  10 06:37:34   104     624  0   13
    FE80::D68C:B5FF:FE6B:DB48
1   Link-local address:      Se0/0/0                  11 06:37:54     1     100  0   38
    FE80::FF:FE00:3
0   Link-local address:      Se0/0/1                  11 06:46:11     1     100  0   30
    FE80::FF:FE00:1
```

```
R1# show ipv6 eigrp topology 2001:DB8:1:3::/64
EIGRP-IPv6 Topology Entry for AS(1)/ID(1.1.1.1) for 2001:DB8:1:3::/64
  State is Passive, Query origin flag is 1, 1 Successor(s), FD is 2172416
  Descriptor Blocks:
  FE80::FF:FE00:3 (Serial0/0/1), from FE80::FF:FE00:3, Send flag is 0x0
      Composite metric is (2172416/28160), route is Internal
      Vector metric:
        Minimum bandwidth is 1544 Kbit
        Total delay is 20100 microseconds
        Reliability is 255/255
        Load is 1/255
        Minimum MTU is 1500
        Hop count is 1
        Originating router is 3.3.3.3
  FE80::FF:FE00:2 (Serial0/0/0), from FE80::FF:FE00:2, Send flag is 0x0
      Composite metric is (2684416/2172416), route is Internal
      Vector metric:
        Minimum bandwidth is 1544 Kbit
        Total delay is 40100 microseconds
        Reliability is 255/255
        Load is 1/255
        Minimum MTU is 1500
        Hop count is 2
```



```
R1# show ipv6 route
IPv6 Routing Table - default - 13 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, R - RIP, I1 - ISIS L1, I2 - ISIS L2
       IA - ISIS interarea, IS - ISIS summary, D - EIGRP, EX - EIGRP external
       ND - Neighbor Discovery, l - LISP
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
C   2001:DB8:1:1::/64 [0/0]
     via GigabitEthernet0/0, directly connected
L   2001:DB8:1:1::1/128 [0/0]
     via GigabitEthernet0/0, receive
D   2001:DB8:1:2::/64 [90/2172416]
     via FE80::FF:FE00:2, Serial0/0/0
D   2001:DB8:1:3::/64 [90/2172416]
     via FE80::FF:FE00:3, Serial0/0/1
C   2001:DB8:1:4::/64 [0/0]
     via Serial0/0/1, directly connected
L   2001:DB8:1:4::1/128 [0/0]
     via Serial0/0/1, receive
C   2001:DB8:1:5::/64 [0/0]
     via Serial0/0/0, directly connected
L   2001:DB8:1:5::1/128 [0/0]
     via Serial0/0/0, receive
D   2001:DB8:1:6::/64 [90/2681856]
     via FE80::FF:FE00:3, Serial0/0/1
     via FE80::FF:FE00:2, Serial0/0/0
D   2001:DB8:1:7::/64 [90/2681856]
     via FE80::FF:FE00:3, Serial0/0/1
D   2001:DB8:1:8::/64 [90/2681856]
     via FE80::FF:FE00:2, Serial0/0/0
D   2001:DB8:1:33::/64 [90/2684416]
     via FE80::FF:FE00:3, Serial0/0/1
     via FE80::FF:FE00:2, Serial0/0/0
L   FF00::/8 [0/0]
     via Null0, receive
```

```
 [13:22][cisco@NMS~ ]$ snmpget -v2c -c community 10.250.250.14
1.3.6.1.4.1.9.2.1.58.0
SNMPv2-SMI::enterprises.9.2.1.58.0 = INTEGER: 11
```

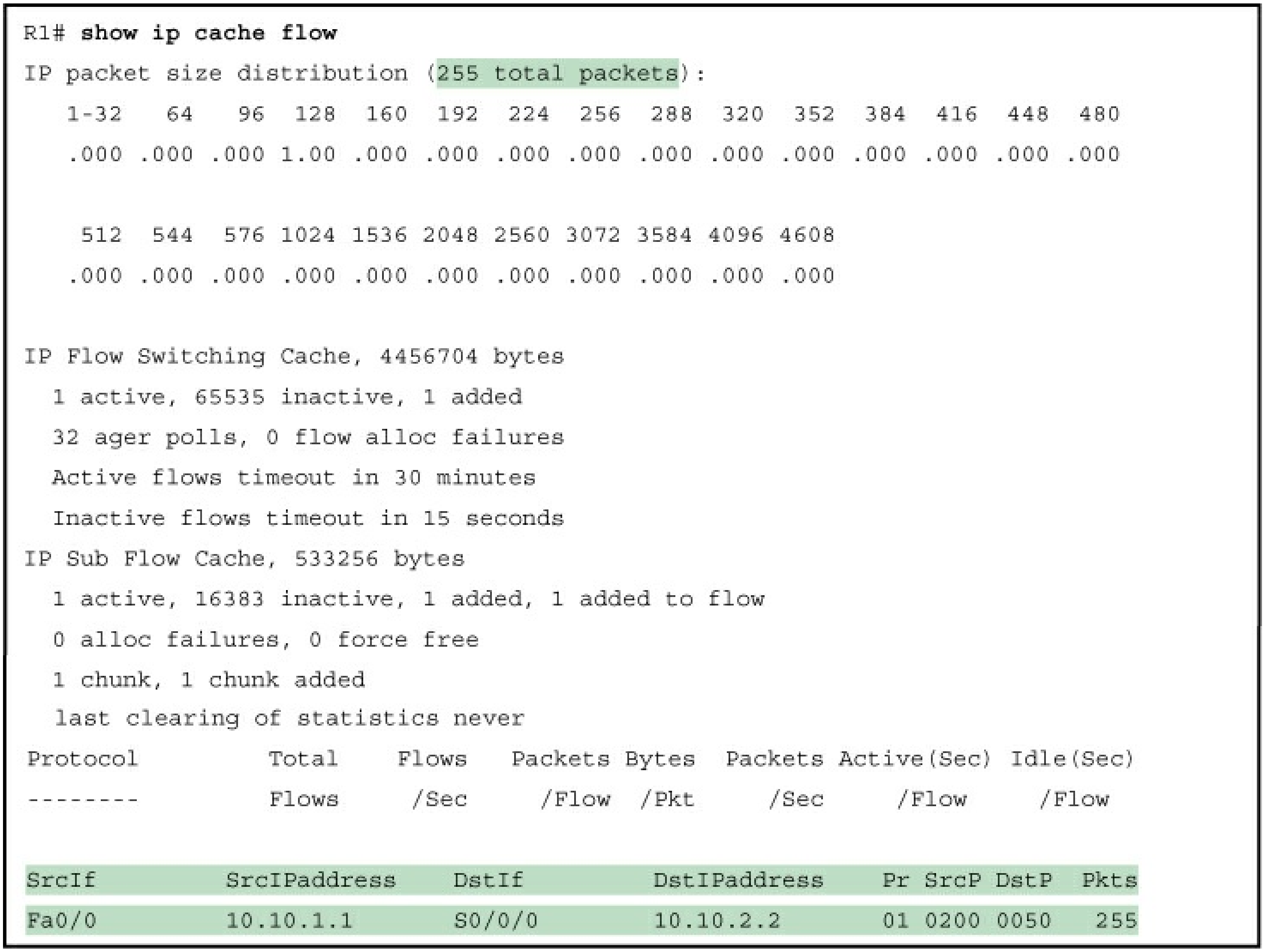
```
R1(config)# ip access-list standard ACL_PROTECTSNMP
R1(config-std-nacl)# permit host 10.10.10.101
R1(config-std-nacl)# exit
R1(config)# snmp-server community V01leyB@1l!!! RO ACL_PROTECTSNMP
R1(config)# snmp-server location Tampa
R1(config)# snmp-server contact Anthony Sequeira
R1(config)# end
R1#
```

```
R2(config)# ip access-list standard ACL_PROTECTSNMP
R2(config-std-nacl)# permit host 10.20.20.201
R2(config-std-nacl)# exit
R2(config)# snmp-server community T3nn1sB@ll RW ACL_PROTECTSNMP
R2(config)# snmp-server location New York
R2(config)# snmp-server contact John Sequeira
R2(config)# end
R2#
```

```
R1(config)# no service timestamps
R1(config)# service sequence-numbers
R1(config)# end
R1#
000011: %SYS-5-CONFIG_I: Configured from console by console
```

```
R1# show logging
Syslog logging: enabled (0 messages dropped, 2 messages rate-limited,0 flushes, 0
overruns, xml disabled, filtering disabled)
No Active Message Discriminator.
No Inactive Message Discriminator.
Console logging: level debugging, 10 messages logged, xml disabled, filtering disabled
Monitor logging: level debugging, 0 messages logged, xml disabled, filtering disabled
Buffer logging:  level debugging, 10 messages logged, xml disabled,filtering disabled
Logging Exception size (8192 bytes)
Count and timestamp logging messages: disabled
Persistent logging: disabled
No active filter modules.
ESM: 0 messages dropped
Trap logging: level informational, 13 message lines logged
Log Buffer (8192 bytes):
*Dec 18 17:10:14.079: %LINK-3-UPDOWN: Interface FastEthernet0/0, changed state to down
*Dec 18 17:10:15.079: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet0/0,
changed state to down
...
```

```
R1(config)# interface fastethernet0/0
R1(config-if)# ip flow ingress
R1(config-if)# ip flow egress
R1(config-if)# exit
R1(config)# ip flow-export destination 10.1.10.100 99
R1(config)# ip flow-export version 9
R1(config)# ip flow-export source loopback 0
R1(config)# end
R1#
```



```
R1# show ip cache flow
IP packet size distribution (255 total packets):
   1-32   64   96  128  160  192  224  256  288  320  352  384  416  448  480
   .000 .000 .000 1.00 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000


    512  544  576 1024 1536 2048 2560 3072 3584 4096 4608
   .000 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000


IP Flow Switching Cache, 4456704 bytes
  1 active, 65535 inactive, 1 added
  32 ager polls, 0 flow alloc failures
  Active flows timeout in 30 minutes
  Inactive flows timeout in 15 seconds
IP Sub Flow Cache, 533256 bytes
  1 active, 16383 inactive, 1 added, 1 added to flow
  0 alloc failures, 0 force free
  1 chunk, 1 chunk added
  last clearing of statistics never
Protocol         Total    Flows   Packets Bytes  Packets Active(Sec) Idle(Sec)
--------         Flows     /Sec     /Flow  /Pkt     /Sec     /Flow     /Flow

SrcIf          SrcIPaddress    DstIf          DstIPaddress    Pr SrcP DstP  Pkts
Fa0/0          10.10.1.1       S0/0/0         10.10.2.2       01 0200 0050   255
```

```
R1# show ip flow interface
FastEthernet0/0
  ip flow ingress
  ip flow egress

R1# show ip flow export
Flow export v9 is enabled for main cache
  Export source and destination details :
  VRF ID : Default
   Source(1)       1.1.1.1 (Loopback0)
   Destination(1)  10.1.10.100 (99)
  Version 9 flow records
  0 flows exported in 0 udp datagrams
  0 flows failed due to lack of export packet
  0 export packets were sent up to process level
  0 export packets were dropped due to no fib
  0 export packets were dropped due to adjacency issues
  0 export packets were dropped due to fragmentation failures
  0 export packets were dropped due to encapsulation fixup failures
R1#
```

```
R2# copy tftp flash
Address or name of remote host []? 2.2.2.1
Source filename []? c2900-universalk9-mz.SPA.152-4.M1.bin
Destination filename [c2900-universalk9-mz.SPA.152-4.M1.bin]?
Accessing tftp://2.2.2.1/c2900-universalk9-mz.SPA.152-4.M1.bin...
Loading c2900-universalk9-mz.SPA.152-4.M1.bin from 2.2.2.1 (via GigabitEthernet0/1):
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
[OK - 74503236 bytes]


74503236 bytes copied in 187.876 secs (396555 bytes/sec)
R2#
```

```
R2# show flash
-#- --length-- -----date/time------ path
1     74503236 Feb 12 2013 19:06:54 +00:00 c2900-universalk9-mz.SPA.151-4.M4.bin
2     97794040 Sep 21 2012 14:02:50 +00:00 c2900-universalk9-mz.SPA.152-4.M1.bin

78909440 bytes available (172297280 bytes used)
```

```
R2# show version
Cisco IOS Software, C2900 Software (C2900-UNIVERSALK9-M), Version 15.2(4)M1, RELEASE
SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
Copyright  1986-2012 by Cisco Systems, Inc.
Compiled Thu 26-Jul-12 20:54 by prod_rel_team
ROM: System Bootstrap, Version 15.0(1r)M15, RELEASE SOFTWARE (fc1)

R2 uptime is 44 minutes
System returned to ROM by reload at 19:44:01 UTC Tue Feb 12 2013
System restarted at 19:45:53 UTC Tue Feb 12 2013
System image file is "flash:c2900-universalk9-mz.SPA.152-4.M1.bin"
Last reload type: Normal Reload
Last reload reason: Reload Command



This product contains cryptographic features and is subject to United
States and local country laws governing import, export, transfer and
use. Delivery of Cisco cryptographic products does not imply
third-party authority to import, export, distribute or use encryption.
Importers, exporters, distributors and users are responsible for
compliance with U.S. and local country laws. By using this product you
agree to comply with applicable laws and regulations. If you are unable
to comply with U.S. and local laws, return this product immediately.
```

```
A summary of U.S. laws governing Cisco cryptographic products may be found at:
http://www.cisco.com/wwl/export/crypto/tool/stqrg.html

If you require further assistance please contact us by sending email to
export@cisco.com.

Cisco CISCO2901/K9 (revision 1.0) with 483328K/40960K bytes of memory.
Processor board ID FTX1628837T
2 Gigabit Ethernet interfaces
4 Serial(sync/async) interfaces
1 terminal line
DRAM configuration is 64 bits wide with parity enabled.
255K bytes of non-volatile configuration memory.
3425968K bytes of USB Flash usbflash1 (Read/Write)
250880K bytes of ATA System CompactFlash 0 (Read/Write)


License Info:

License UDI:

-------------------------------------------------
Device#   PID                   SN
-------------------------------------------------
*0        CISCO2901/K9          FTX1628837T



Technology Package License Information for Module:'c2900'

-----------------------------------------------------------------
Technology    Technology-package           Technology-package
              Current       Type           Next reboot
------------------------------------------------------------------
ipbase        ipbasek9      Permanent      ipbasek9
security      None          None           None
uc            None          None           None
data          None          None           None

Configuration register is 0x2102
```

```
R1#! 1) User walks to the router and powers off the router

! 2) User removes all flash memory

! 3) User turns router back on again


System Bootstrap, Version 15.0(1r)M15, RELEASE SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
Copyright  2011 by cisco Systems, Inc.

Total memory size = 512 MB - On-board = 512 MB, DIMM0 = 0 MB
CISCO2901/K9 platform with 524288 Kbytes of main memory
Main memory is configured to 72/-1(On-board/DIMM0) bit mode with ECC enabled

! 4) Several lines of messages omitted: ROMMON initializing

Readonly ROMMON initialized
 rommon 1 > confreg 0x2142

 You must reset or power cycle for new config to take effect
 rommon 2 >
 ! 6) User walks to the router and plugs the flash back in.
```

```
rommon 3 > reset

System Bootstrap, Version 15.0(1r)M15, RELEASE SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
Copyright  2011 by cisco Systems, Inc.

Total memory size = 512 MB - On-board = 512 MB, DIMM0 = 0 MB
CISCO2901/K9 platform with 524288 Kbytes of main memory
Main memory is configured to 72/-1(On-board/DIMM0) bit mode with ECC enabled

! Lots of IOS initialization messages omitted



         --- System Configuration Dialog ---

Would you like to enter the initial configuration dialog? [yes/no]: no




Press RETURN to get started!

! 9) User logs in at the console and sets a new enable secret password.

```

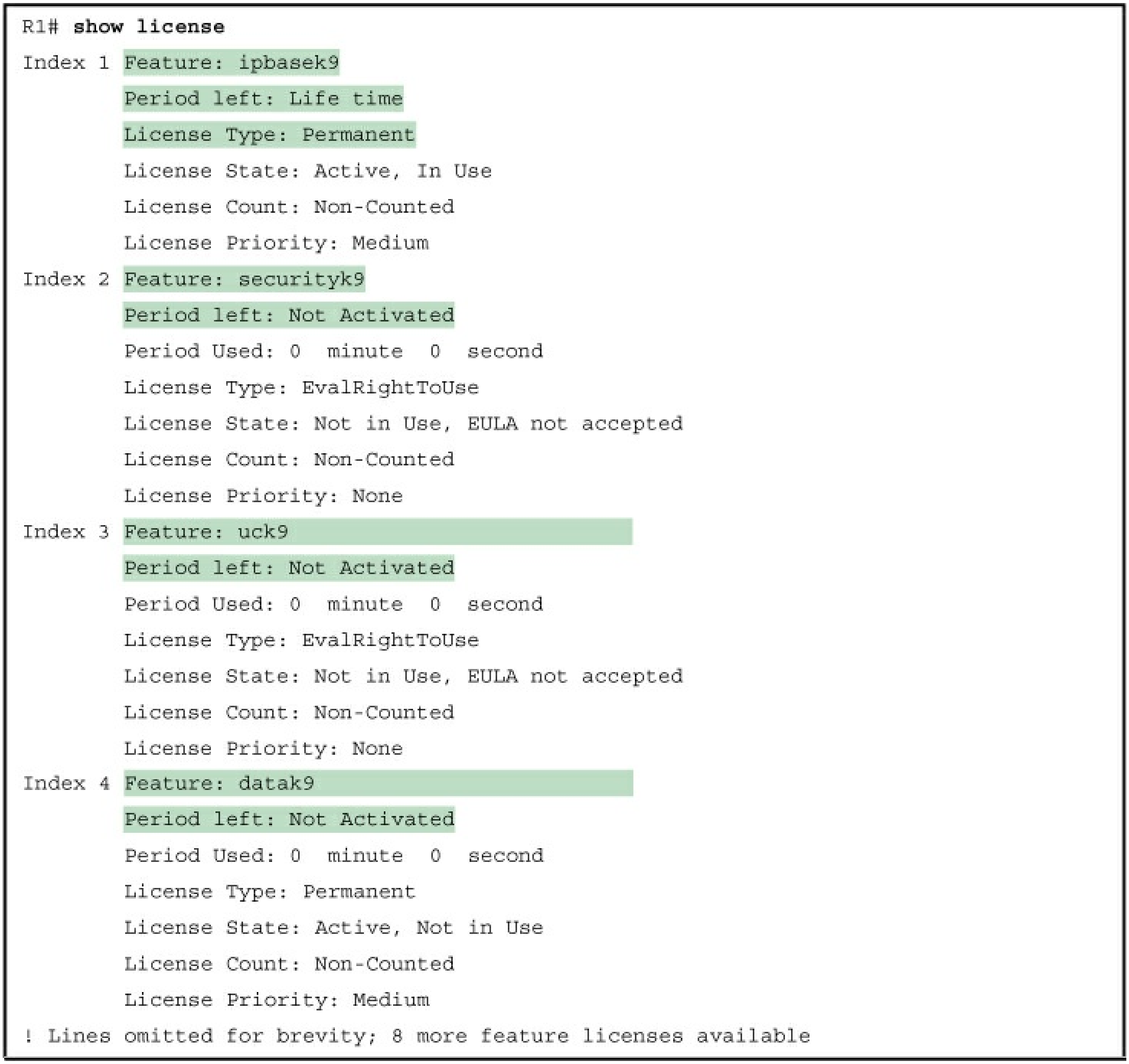
```
Router>
Router>enable

! 10) User copies the starting config to make the router do its normal job
Router# copy startup-config running-config
Destination filename [running-config]?
3297 bytes copied in 0.492 secs (6701 bytes/sec)

! 11) User changes the forgotten enable secret password
R1# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R1(config)# enable secret cisco
R1(config)# ^Z
R1#

! 12) User saves his changes to the password
R1# copy running-config startup-config
Destination filename [startup-config]?
3297 bytes copied in 0.492 secs (6701 bytes/sec)

! 13) User changes the config register back to its normal 0x2102
R1# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R1(config)# config-reg 0x2102
R1(config)# ^Z
R1#
```

```
! Step 1 next (two commands)
!
hannah# show running-config
! (lines omitted)
hostname hannah
! (rest of lines omitted)

hannah# show startup-config
! (lines omitted)
hostname hannah
! (rest of lines omitted)

! Step 2 next. Notice that the command prompt changes immediately after
! the hostname command.
!
hannah# configure terminal
hannah(config)# hostname kris
kris(config)# exit
! Step 3 next (two commands)
!
kris# show running-config
! (lines omitted)
hostname kris
! (rest of lines omitted - notice that the running configuration reflects the
!  changed hostname)

kris# show startup-config
! (lines omitted)
hostname hannah
! (rest of lines omitted - notice that the changed configuration is not
! shown in the startup config)
```

```
copy {tftp | running-config | startup-config} {tftp | running-config |
  startup-config}
```

```
R1# copy running-config usbflash1:temp-copy-of-config
Destination filename [temp-copy-of-config]?
3159 bytes copied in 0.944 secs (3346 bytes/sec)


R1# dir usbflash1:
Directory of usbflash1:/


    1  -rw-        4096  Feb 11 2013 17:17:00 +00:00  ._.Trashes
    2  drw-           0  Feb 11 2013 17:17:00 +00:00  .Trashes
    7  drw-           0  Feb 11 2013 17:17:00 +00:00  .Spotlight-V100
   73  -rw-    97794040  Feb 12 2013 21:49:36 +00:00  c2900-universalk9-mz.SPA.152-4.
M1.bin
   74  -rw-        3159  Feb 12 2013 22:17:00 +00:00  temp-copy-of-config


7783804928 bytes total (7685111808 bytes free)
R1#
```

```
R1# show license udi
Device#   PID                   SN              UDI
-----------------------------------------------------------------------------
*0        CISCO2901/K9          FTX162883H0     CISCO2901/K9:FTX162883H0
```



```
R1# show license
Index 1 Feature: ipbasek9
        Period left: Life time
        License Type: Permanent
        License State: Active, In Use
        License Count: Non-Counted
        License Priority: Medium
Index 2 Feature: securityk9
        Period left: Not Activated
        Period Used: 0  minute  0  second
        License Type: EvalRightToUse
        License State: Not in Use, EULA not accepted
        License Count: Non-Counted
        License Priority: None
Index 3 Feature: uck9
        Period left: Not Activated
        Period Used: 0  minute  0  second
        License Type: EvalRightToUse
        License State: Not in Use, EULA not accepted
        License Count: Non-Counted
        License Priority: None
Index 4 Feature: datak9
        Period left: Not Activated
        Period Used: 0  minute  0  second
        License Type: Permanent
        License State: Active, Not in Use
        License Count: Non-Counted
        License Priority: Medium
! Lines omitted for brevity; 8 more feature licenses available
```

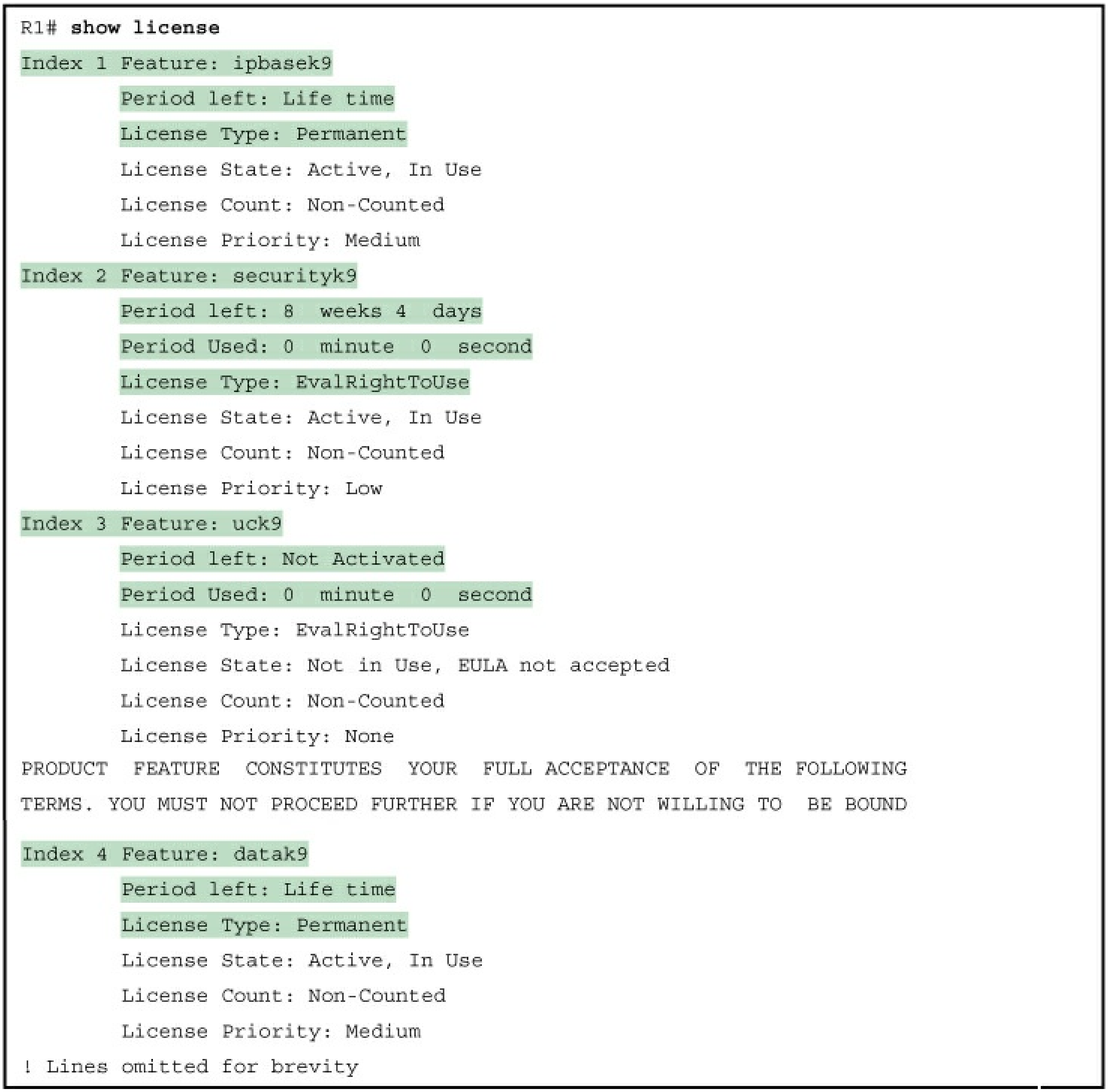
```
R1# show license feature

Feature name       Enforcement  Evaluation  Subscription    Enabled  RightToUse
ipbasek9           no           no          no              yes      no
securityk9         yes          yes         no              no       yes
uck9               yes          yes         no              no       yes
datak9             yes          yes         no              no       yes
gatekeeper         yes          yes         no              no       yes
SSL_VPN            yes          yes         no              no       yes
ios-ips-update     yes          yes         yes             no       yes
SNASw              yes          yes         no              no       yes
hseck9             yes          no          no              no       no
cme-srst           yes          yes         no              no       yes
WAAS_Express       yes          yes         no              no       yes
UCVideo            yes          yes         no              no       yes

R1# show version
Cisco IOS Software, C2900 Software (C2900-UNIVERSALK9-M), Version 15.1(4)M4, RELEASE
SOFTWARE (fc1)

! Lines omitted for brevity
License UDI:
-------------------------------------------------


Device#     PID                        SN
-------------------------------------------------
*0          CISCO2901/K9             FTX1628838P



Technology Package License Information for Module:'c2900'


-----------------------------------------------------------------
Tecnology     Technology-package            Technology-package
               Current       Type            Next reboot
------------------------------------------------------------------
ipbase         ipbasek9      Permanent       ipbasek9
security       None          None            None
uc             None          None            None
data           None          None            None

Configuration register is 0x2102
```

```
R1# dir usbflash1:
Directory of usbflash1:/
    1  -rw-        4096  Feb 11 2013 17:17:00  FTX1628838P_201302111432454180.lic


7783804928 bytes total (7782912000 bytes free)


R1# license install usbflash1:FTX1628838P_201302111432454180.lic


Installing...Feature:datak9...Successful:Supported
1/1 licenses were successfully installed
0/1 licenses were existing licenses
0/1 licenses were failed to install
R1#
Feb 11 22:35:20.786: %LICENSE-6-INSTALL: Feature datak9 1.0 was installed in this
device. UDI=CISCO2901/K9:FTX1628838P; StoreIndex=1:Primary License Storage


Feb 11 22:35:21.038: %IOS_LICENSE_IMAGE_APPLICATION-6-LICENSE_LEVEL: Module name =
c2900 Next reboot level = datak9 and License = datak9
```

```
R1# show license
Index 1 Feature: ipbasek9
        Period left: Life time
        License Type: Permanent
        License State: Active, In Use
        License Count: Non-Counted
        License Priority: Medium
Index 2 Feature: securityk9
        Period left: Not Activated
        Period Used: 0  minute  0  second
        License Type: EvalRightToUse
        License State: Not in Use, EULA not accepted
        License Count: Non-Counted
        License Priority: None
Index 3 Feature: uck9
        Period left: Not Activated
        Period Used: 0  minute  0  second
        License Type: EvalRightToUse
        License State: Not in Use, EULA not accepted
        License Count: Non-Counted
        License Priority: None
Index 4 Feature: datak9
        Period left: Life time
        License Type: Permanent
        License State: Active, In Use
        License Count: Non-Counted
        License Priority: Medium
! Lines omitted for brevity
```

```
R1# show version | begin Technology Package
Technology Package License Information for Module:'c2900'

-----------------------------------------------------------------
Technology    Technology-package           Technology-package
              Current       Type           Next reboot
------------------------------------------------------------------
ipbase        ipbasek9      Permanent      ipbasek9
security      securityk9    None           None
uc            None          None           None
data          datak9        Permanent      datak9

Configuration register is 0x2102
```

```
R1(config)# license boot module c2900 technology-package securityk9

PLEASE  READ THE  FOLLOWING TERMS  CAREFULLY. INSTALLING THE LICENSE OR
LICENSE  KEY  PROVIDED FOR  ANY CISCO  PRODUCT  FEATURE  OR  USING SUCH
PRODUCT  FEATURE  CONSTITUTES  YOUR  FULL ACCEPTANCE  OF  THE FOLLOWING
TERMS. YOU MUST NOT PROCEED FURTHER IF YOU ARE NOT WILLING TO  BE BOUND
BY ALL THE TERMS SET FORTH HEREIN.

! The rest of the EULA is omitted…

Activation  of the  software command line interface will be evidence of
your acceptance of this agreement.



ACCEPT? [yes/no]: yes
% use 'write' command to make license boot config take effect on next boot

Feb 12 01:35:45.060: %IOS_LICENSE_IMAGE_APPLICATION-6-LICENSE_LEVEL: Module name =
c2900 Next reboot level = securityk9 and License = securityk9
Feb 12 01:35:45.524: %LICENSE-6-EULA_ACCEPTED: EULA for feature securityk9 1.0 has
been accepted. UDI=CISCO2901/K9:FTX1628838P; StoreIndex=0:Built-In License Storage
R1(config)# ^Z
```



```
R1# show license
Index 1 Feature: ipbasek9
        Period left: Life time
        License Type: Permanent
        License State: Active, In Use
        License Count: Non-Counted
        License Priority: Medium
Index 2 Feature: securityk9
        Period left: 8  weeks 4  days
        Period Used: 0  minute  0  second
        License Type: EvalRightToUse
        License State: Active, In Use
        License Count: Non-Counted
        License Priority: Low
Index 3 Feature: uck9
        Period left: Not Activated
        Period Used: 0  minute  0  second
        License Type: EvalRightToUse
        License State: Not in Use, EULA not accepted
        License Count: Non-Counted
        License Priority: None
PRODUCT  FEATURE  CONSTITUTES  YOUR  FULL ACCEPTANCE  OF  THE FOLLOWING
TERMS. YOU MUST NOT PROCEED FURTHER IF YOU ARE NOT WILLING TO  BE BOUND

Index 4 Feature: datak9
        Period left: Life time
        License Type: Permanent
        License State: Active, In Use
        License Count: Non-Counted
        License Priority: Medium
! Lines omitted for brevity
```